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TECHNICAL DOCUMENT 3104
March 2000

CHIEF2000 Users Manual

G. W. Benthien
D. Barach
S. Hobbs

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ADMINISTRATIVE INFORMATION

This document was prepared for the Office of Naval Research, Sources and Arrays (ONR 321), under the direction of Jan F. Lindberg (Program Officer, Acoustic Transducers) by the Acoustic Technology & Analysis Branch (D711), SSC San Diego.

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1. INTRODUCTION

This user guide explains the new CHIEF2000 computer program. The program was tested on machines running Windows 95/98®, Windows NT®, and DEC OSF1. The CHIEF program was originally developed in the 1960s to compute the acoustic radiation from an arbitrary shaped radiating body. The program was extensively updated in 1988 and a users manual was published [Benthien, Barach, and Gillette, 1988]. This CHIEF manual is still an excellent reference for those interested in the details of the CHIEF program and the underlying theory. The CHIEF manual was included in the recently released CD-ROM document [Benthien and Barach, 1998]. The appendix summarizes CHIEF program theory.

The original CHIEF program and the 1988 update were essentially a library of Fortran subroutines that were called from a user-generated control routine. This approach allowed the user more flexibility, but required a Fortran compiler to compile and link the control routine with the library routines. The presence of a Fortran compiler was not a big problem on most main frame computers. However, with the increasing use of PCs and workstations for numerical computation, the presence of a Fortran compiler could no longer be assumed. Thus, the new CHIEF 2000 program is a compiled executable program that relies on a user-generated ASCII text file for input. While this approach gives up some flexibility, we have included as many features of the previous versions of CHIEF as possible.

This user guide describes the setup of the user-generated input file. Section 2 describes the use of the program and the general organization of the input file. Sections 3–5 describe the main subdivisions of the input file. Section 3 describes the parameter section in which the user can define parameters for use in the remaining sections of the input file. Section 4 describes the geometry input section in which the user specifies the radiating surface and its subdivision. Section 5 describes the control section in which the user specifies the quantities to be computed and the form of the output. Section 6 describes the format of the various possible output files. Section 7 contains many example problems along with the corresponding input files.

Much of the material in this user-guide is reference material; therefore this document is not designed to be read from start to finish as one would read a novel. The authors feel that the program can be best learned by studying the example problems near the end of the manual. A suggested reading plan is given below:

1. Read Introduction.
2. Read General Organization section.
3. Read Parameter section.
4. Read introductory portions of the Geometry and Control sections.
5. Work through example problems.
6. Refer to the command descriptions in the Geometry and the Control sections as needed.

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2. GENERAL ORGANIZATION

The program can be run by typing the command

```
chief <input file name>.inp
```

at the command prompt. In Windows 95/98® or Windows NT®, the user should go to an MS-DOS® window to enter the command. The input file name can be any legal DOS file name (maximum of eight characters with no spaces). The .inp extension can be omitted in the command line. If the run completes normally, the message **Normal Termination** will appear on the screen.

The input file (<input file name>.inp) is an ASCII text file generated by the user. It must not contain any control characters. The file is divided into the following three major sections:

1. Parameter definition
2. Geometry specification
3. Control logic

In the parameter section, the user can assign parameter names to values required for input in the following sections. The parameter definitions can involve arithmetic expressions as well as previously defined parameters. It is not necessary to define any parameters since all required input values can be either parameters or numerical values. The parameter section is provided for the user's convenience. In the geometry section, the user specifies the radiating surface, the subdivision of the surface, and any symmetry conditions. In the control logic section, the user can specify the quantities to be computed, provide necessary input data, and specify the type of output. A sample input file is shown below.

```

! Parameter section

nblks=8
rotlim=pi/nblks
radius=1.2e-1    ! radius of sphere
freq1=100
frequ=200
freqinc=10
end*parameters

! Geometry section

rotational,nblks
sphere,radius
0,pi,-rotlim,rotlim
12,1,4,16
3,0,0,0
end*geometry

! Control logic section

frequency,freq1,frequ,freqinc
fluid,995,1489
rhs symmetry
velocities,sample.vel
surface pressures,1
far-field,1,3
0,90,5,0,0,0

```

A detailed explanation of each input-file section will be given later. Note that the parameter definition section must be terminated with a statement beginning with `end*p` and the geometry section must be terminated with a statement beginning with `end*g`. The control logic section is terminated by an end of file. Blank lines are ignored in the input file, as are any comments. Comments must begin with an exclamation point (!). All commands and parameters are case insensitive. Thus, `NBLKS` is the same parameter as `nblks`, and `Sphere` is the same command as `sphere`. It is also important that consistent units be used for all input quantities. The program by default takes the fluid density and sound speed to be 1000 Kg/m³ and 1500 m/sec. If the user desires to use a system of units other than mks, then these quantities must be changed to values appropriate for that system of units. Data read in from files must also be in the chosen consistent set of units.

Unlike the original version of CHIEF, this new version has very few predetermined size limits. Most arrays used by the program are allocated dynamically within the program based on inputs in the input file. There are a few arrays, however, that are still statically dimensioned. Thus, the maximum size of these arrays cannot be exceeded without modifying the program and recompiling. Table 1 shows these limits. We do not feel that these limits should impose any serious limitations.

Table 1. Array size limits in CHIEF2000.

Maximum finite element node number	5000
Maximum number of interior points	100
Maximum number of point sources in point source check	100
Maximum number of Gaussian quadrature points on a surface subdivision in either of the two surface coordinate directions	64
Maximum total number of Gaussian quadrature points on a surface subdivision	512
Maximum order of rotational symmetry	120

In addition to any user-specified output files, the program always creates a file with the name `<input file name>.out` that contains an echo of all input file lines, error diagnostics, and user-specified output. In the parameter and geometry sections, the program finds as many input errors as it can before stopping. However, the program does not go on to the next section if there are any errors found in the current section. In the control section, the program terminates if any input error is found. Termination helps prevent calculations from being performed with inconsistent or missing input.

The program can generate many output files. These files all have the same root file name as the input file. Table 2 lists the extensions of these output files along with a brief description of their contents.

Table 2. Possible output files.

File Extension	File Type	File Contents
.sps	ASCII	Surface pressures on each subdivision
.ffp	ASCII	Far-field angles and pressures
.nfp	ASCII	Near-field coordinates and pressures
.zmx	Binary	Radiation impedance matrix
.pmf	Binary	Far-field pattern matrix
.pmn	Binary	Near-field pattern matrix
.abs	Binary	A and B surface matrices
.abf	Binary	A and B far-field matrices
.abn	Binary	A and B near-field matrices

3. PARAMETER SECTION

In the parameter section, the user can define parameters that can be used elsewhere in the CHIEF ASCII input file in place of numerical inputs. Only a single parameter may be defined on each line of the parameter section, and the parameter definition must have the form

`<parameter name>=<expression>.`

The parameter name may be any sequence of alpha-numeric characters or underscore characters (`_`) subject to the following restrictions:

- The first character must be a letter.
- The length of the parameter name can not exceed 24 characters.
- The parameter name cannot contain any spaces.

Case is not important in parameter names (e.g., `Nblks` is the same as `nblks`).

All parameter values are interpreted by the program as real numbers. However, the nearest integer is used in places where an integer input is expected. The user may insert comments on a separate line or at the end of a line by preceding the comment with an exclamation point (!).

The expression on the right-hand side is subject to the following conditions:

- The four arithmetic operations (`+`, `-`, `*`, `/`) and exponentiation (`^`) are allowed.
- The sine or cosine of an arithmetic expression is allowed (i.e., `sin(x^2)` or `cos(x+y)`).
- The operands can be numerical values or previously defined parameters.
- Parenthetical grouping (`...`) and nested operations may be used.
- An exponent may be any real number.
- Scientific notation is allowed (i.e., `1.6e-6`).
- The entire line must not exceed 132 characters.

Expressions satisfying the above conditions are also allowed in the geometry and the control sections wherever a numeric input is expected.

Spaces may be freely used in parameter definitions except within parameter names. The program ignores them. There is one parameter, `pi`, that has been predefined by the program and may be used anywhere in the input file, including the definition of other parameters. The usual rules for precedence of operations apply, for example,

- Operators of equal precedence are evaluated in the usual left to right order.
- Exponentiation has precedence over addition, subtraction, multiplication, and division.
- Multiplication and division have precedence over addition and subtraction.
- Unary plus and minus operations (i.e., -1.0 or +5.6) have the same precedence as exponentiation.

The parameter section must end with a line whose first five nonblank characters are `end*p`. The following is an example of a valid parameter section.

```
rho=1000
c=1500.

diam      =  1.5e2      ! This is a comment
height    =  4.67
length1   =  ((height*.5)^2+(diam/2)^2)^.5
length2   =  length1^(1/2)

theta_upper=pi/4
costu=cos(theta_upper)
theta_lower=-theta_upper

freq_upper=3e3
freq_lower=freq_upper*1e-1

near_field_r=length1*c/freq_lower
near_field_theta=pi*5E-1

end*parameters
```

The following example contains some invalid parameter definitions.

```
rho fluid=1000                (space in name)
c(1)=1500                     (parenthesis in name)
height=4.67 width=2.0         (more than one parameter on line)
length1=((height*.5)^2+(diam/2)^2)^.5
    (parameter used on the right side before its definition)
1diam=1.5,                   (name begins with a numeral and comma illegal)
inner*radius=.5              (* illegal symbol in name)
outer-radius=2.5             (- illegal symbol in name)
end*param
```

A line specifying the end of the parameter section (i.e., `end*params`) must be included even if no parameters are defined.

4. GEOMETRY SECTION

CHIEF calculates radiation from one or more closed surfaces in 3-space, or from one or more planar regions in an infinite rigid baffle. In this section of the manual, we describe how the user specifies the geometry of the radiating surface. If the surface has one, two, or three planes of reflective symmetry or a finite order of rotational symmetry, then the user only needs to input the portion of the surface corresponding to one symmetry block.

The commands that specify the surface geometry may be given in any order, except the command specifying the symmetry type (NONE, REFLECTIVE, ROTATIONAL) must be the first command in the geometry section. If there are no underscore characters in the command word, the program uses only the first three characters. If there is an underscore character, the program uses the first letter, the underscore character, and the first character after the underscore to specify the command. Other forms of the command words are perfectly valid as long as the three characters specifying the command are the same.

Each command line consists of a command or a command followed by one or more arguments. Some command lines must be followed by additional lines of data. Commands, arguments, and data items are separated by commas. Parameters defined in the parameter section and expressions involving these parameters may be used for any numerical input in this section. As always, blank lines, comments, and spaces are ignored.

CHIEF has many predefined surfaces such as spherical, cylindrical, ellipsoidal, etc. The radiating surface can be defined in terms of portions of several of these predefined surfaces. CHIEF also allows the surface to be defined in terms of nodes and elements as in a finite element problem. The user must supply inputs specifying the various nonoverlapping surface regions that make up the total radiating surface. In the case of finite element type input, each element is considered as a separate surface region. Each surface region is defined by a one-to-one smooth mapping from a rectangular planar region into 3-dimensional space. The points on the surface as well as any field points are defined in terms of a global rectangular Cartesian coordinate system, x_1, x_2, x_3 . Points in the base rectangular region are defined in terms a pair of coordinates, u, v . The values u and v are sometimes called surface coordinates. Each surface region is defined by three relations of the form:

$$x_1 = x_1(u, v) \quad x_2 = x_2(u, v) \quad x_3 = x_3(u, v).$$

Each predefined geometry is actually defined in terms of a local x, y, z Cartesian coordinate system that is related to the global coordinate system by a translation and/or a cyclic permutation of the coordinate axes. The translation is specified by a vector, \vec{t} , from the global origin to the local origin. The cyclic permutation of the coordinate axes is specified by giving the axis (I_z) in the global system that corresponds to the z -axis in the local system. The user input for this specification is the integer I_z . Figures 1-3 show the relation between the global and local coordinate systems for $I_z = 1, 2, 3$. Note that $I_z = 3$ corresponds to no rotation at all.

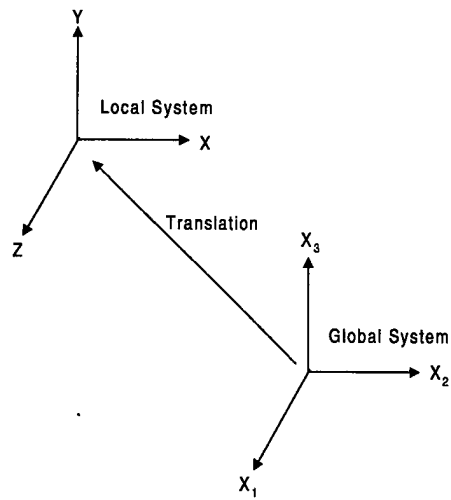


Figure 1. Global and local coordinate systems for $I_z = 1$.

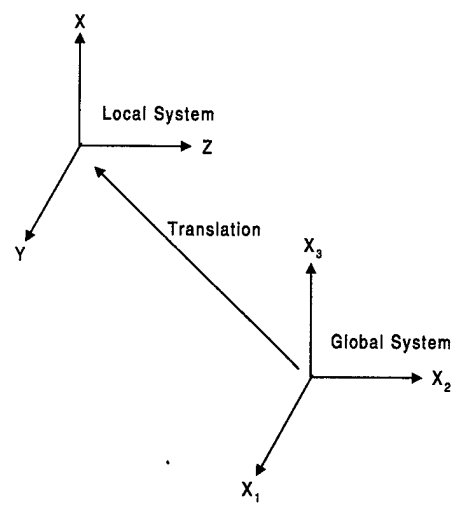


Figure 2. Global and local coordinate systems for $I_z = 2$.

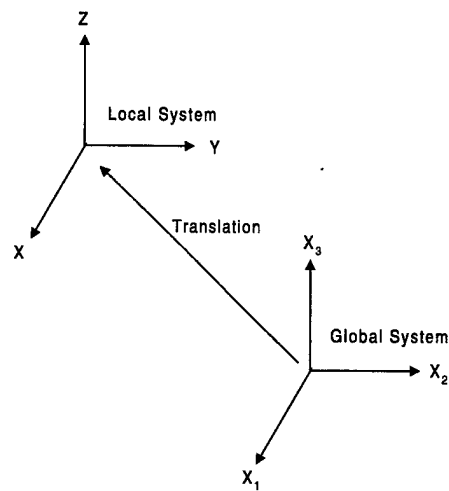


Figure 3. Global and local coordinate systems for $I_z = 3$.

Thus, each surface region is defined by relations of the form:

$$x = x(u, v) \quad y = y(u, v) \quad z = z(u, v),$$

and the specification of I_z and \vec{t} .

In addition to specifying a relation between the local and global coordinate systems, the input quantity I_z is also used to help specify the outward normal vector to the surface region. From the defining equations for a surface region, CHIEF can compute a normal vector at each point of the region, but it cannot determine whether this normal vector is inward or outward. The user specifies this by the sign of I_z . A plus sign accepts the choice made by the CHIEF program and a minus sign reverses the direction of the surface normal on this surface region. For example, in the case of a circular planar surface region, the program computes the normal pointing in the positive z -direction. This direction may or may not be the correct choice for the surface region under consideration. If the radiating surface was like a tin can with axis of rotation along the z -axis, then the outward normal would be in the positive z -direction on the top, but in the negative z -direction on the bottom. Thus, the user would specify a negative I_z for the bottom surface. The user can also specify a breakup of each surface region into subareas (on which the pressure and normal velocity will be assumed constant) by specifying a uniform breakup in the uv rectangular region. Conventional wisdom says that all subdivisions should be less than $1/4$ wavelength with something on the order of $1/8$ wavelength desirable. As far as integration over the subdivisions, four Gaussian quadrature points in $1/8$ wavelength seems to give sufficient accuracy.

The first statement in the geometry section must be one of the CHIEF symmetry options (ROTATIONAL, REFLECTIVE, or NONE) along with any associated parameters such as the number of planes of reflective symmetry. Following the symmetry specification, the surface regions may be defined in any order. However, the ordering will influence the numbering of the subdivisions. The numbering begins with the first region specified and continues consecutively with the other regions in the order specified. Within a region, the numbering starts with the subarea having the smallest u, v values. The numbering continues through the region in the direction of increasing u and v , with the variation in v occurring before variation in u . Figure 4 shows an example of the numbering for three adjacent planar surface regions.

The numbering proceeds sequentially through the various symmetry blocks and the numbering within each symmetry follows the same pattern as in the first block. The numbering of symmetry blocks for reflective symmetry is shown in tables 3-5.

The geometry section ends with a statement like `end*geometry`, where only the first part, `end*g`, is significant to the program. Commands specifying the surface geometry are described on the following pages. The syntax for each command is given along with a description of the parameters and data items that accompany the command. For commands that do not contain an underline character, the program only looks at the first three letters. For commands that contain an underline character, the program looks at the first character, the underline character, and the first character after the underline character. Alternate forms of the commands are allowed as long as the three significant characters are in the

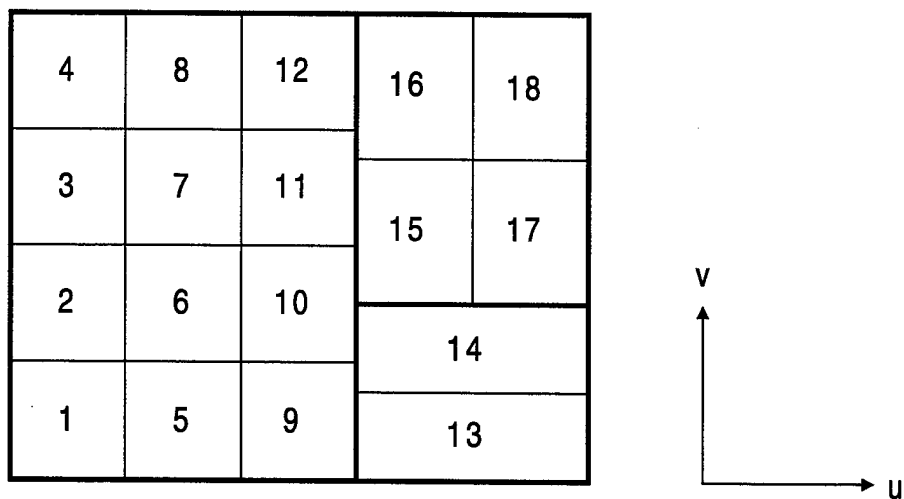


Figure 4. An example of the subdivision numbering scheme.

Table 3. One plane of symmetry ($x_1 = 0$).

Block	Octants		
	x_1	x_2	x_3
1	+	+	+
	+	-	+
	+	-	-
	+	+	-
2	-	+	+
	-	-	+
	-	-	-
	-	+	-

Table 4. Two planes of symmetry ($x_1 = 0$ and $x_2 = 0$).

Block	Octants		
	x_1	x_2	x_3
1	+	+	+
	+	+	-
2	-	+	+
	-	+	-
3	-	-	+
	-	-	-
4	+	-	+
	+	-	-

Table 5. Three planes of symmetry
($x_1 = 0$, $x_2 = 0$, and $x_3 = 0$).

Block	Octants		
	x_1	x_2	x_3
1	+	+	+
2	-	+	+
3	-	-	+
4	+	-	+
5	+	-	-
6	-	-	-
7	-	+	-
8	+	+	-

right place. Optional parameters are enclosed in brackets. For those commands that define a surface region, the mapping from the u , v rectangular region to the surface is described. The user needs to understand what u and v are in order to understand the numbering of the surface subdivisions.

reflective symmetry

specifies planes of reflective symmetry

Command: **reflective symmetry**, N

N Number of planes of reflective symmetry (1,2, or 3)

rotational symmetry

specifies finite order rotational symmetry

Command: **rotational symmetry, N**

N Specifies N -fold rotational symmetry

none

specifies no symmetry

Command: **none**

rectangular_planar

rectangular region on surface parallel to the x, y plane

Command: `rectangular_planar, z0`

u_L, u_U, v_L, v_U

N_u, N_v, Q_u, Q_v

$I_z, [t_1, t_2, t_3]$

z_0	Constant value of z in local coordinate system
u_L, u_U	Lower and upper limits for the surface coordinate u
v_L, v_U	Lower and upper limits for the surface coordinate v
N_u, N_v	Number of subdivisions in the u and v directions in the planar rectangular region
Q_u, Q_v	Number of Gaussian quadrature points per subarea in the u and v directions
I_z	Specifies rotation from local to global coordinate system and orientation of normal
t_1, t_2, t_3	Components of the translation vector from the global origin to the local origin (default is $t_1 = t_2 = t_3 = 0$)

Surface definition:

The local coordinate system must be set up so that the z -axis is normal to the plane of the surface. In this case u is equal to x and v is equal to y . The local coordinates and normal vector are related to the u, v coordinates by

$$\begin{array}{ll} x = u & n_x = 0 \\ y = v & n_y = 0 \\ z = z_0 & n_z = 1 \end{array}$$

circular_planar

circular region on surface parallel to the x, y plane

Command: `circular_planar`, z_0

u_L, u_U, v_L, v_U

N_u, N_v, Q_u, Q_v

$I_z, [t_1, t_2, t_3]$

z_0	Constant value of z in local coordinate system
u_L, u_U	Lower and upper limits for the surface coordinate u
v_L, v_U	Lower and upper limits for the surface coordinate v
N_u, N_v	Number of subdivisions in the u and v directions in the planar rectangular region
Q_u, Q_v	Number of Gaussian quadrature points per subarea in the u and v directions
I_z	Specifies rotation from local to global coordinate system and orientation of normal
t_1, t_2, t_3	Components of the translation vector from the global origin to the local origin (default is $t_1 = t_2 = t_3 = 0$)

Surface definition:

The local coordinate system must be set up so that the z -axis is normal to the plane of the surface. In this case u is the radial distance from the z -axis and v is the angle from the x -axis in the xy plane. The local coordinates and normal vector are related to the u, v coordinates by

$$\begin{aligned}x &= u \cos v & n_x &= 0 \\y &= u \sin v & n_y &= 0 \\z &= z_0 & n_z &= 1\end{aligned}$$

elliptical_planar

elliptical region on surface parallel to the x, y plane

Command: `elliptical_planar`, a, b, z_0

u_L, u_U, v_L, v_U

N_u, N_v, Q_u, Q_v

$I_z, [t_1, t_2, t_3]$

a	Half the length of the major axis of the ellipse
b	Half the length of the minor axis of the ellipse
z_0	Constant value of z in local coordinate system
u_L, u_U	Lower and upper limits for the surface coordinate u
v_L, v_U	Lower and upper limits for the surface coordinate v
N_u, N_v	Number of subdivisions in the u and v directions in the planar rectangular region
Q_u, Q_v	Number of Gaussian quadrature points per subarea in the u and v directions
I_z	Specifies rotation from local to global coordinate system and orientation of normal
t_1, t_2, t_3	Components of the translation vector from the global origin to the local origin (default is $t_1 = t_2 = t_3 = 0$)

Surface definition:

The local coordinate system must be set up so that the z -axis is normal to the plane of the surface. In this case $u = r/f$ where r is the average of the radial distances of a point from the two foci and f is half the interfocal distance. The range of u is $1 \leq u \leq a/\sqrt{a^2 - b^2}$. The family of curves for which u is a constant consists of ellipses having the same foci. The ellipse corresponding to $u = 1$ is the degenerate ellipse consisting of the interval $[-f, f]$ on the x -axis. The ellipse corresponding to $u = a/\sqrt{a^2 - b^2}$ is the boundary ellipse with major diameter of $2a$ and minor diameter of $2b$. Thus, the upper limit u_U of the variable u is almost always $a/\sqrt{a^2 - b^2}$. On an ellipse of constant u the variable v is related to the angle θ from the x -axis in the xy plane by

$$v = \tan^{-1} \left(\frac{u}{\sqrt{u^2 - 1}} \tan \theta \right).$$

The local coordinates and normal vector are related to the u, v coordinates by

$$\begin{aligned} x &= fu \cos v & n_x &= 0, \\ y &= f\sqrt{u^2 - 1} \sin v & n_y &= 0, \\ z &= z_0 & n_z &= 1, \end{aligned}$$

where $f = \sqrt{a^2 - b^2}$.

Equal increments in v do not produce equal increments in θ and vice versa. However, quadrants in the xy -plane do come out the same, as can be seen from the following table:

v	x	y	θ
0	fu	0	0
$\pi/2$	0	$f\sqrt{u^2 - 1}$	$\pi/2$
π	$-fu$	0	π
$3\pi/2$	0	$-f\sqrt{u^2 - 1}$	$3\pi/2$

circular_cylinder

cylindrical surface with axis along z -axis

Command: `circular_cylinder, a`

u_L, u_U, v_L, v_U

N_u, N_v, Q_u, Q_v

$I_z, [t_1, t_2, t_3]$

a	radius of cylinder
u_L, u_U	Lower and upper limits for the surface coordinate u
v_L, v_U	Lower and upper limits for the surface coordinate v
N_u, N_v	Number of subdivisions in the u and v directions in the planar rectangular region
Q_u, Q_v	Number of Gaussian quadrature points per subarea in the u and v directions
I_z	Specifies rotation from local to global coordinate system and orientation of normal
t_1, t_2, t_3	Components of the translation vector from the global origin to the local origin (default is $t_1 = t_2 = t_3 = 0$)

Surface definition:

The local coordinate system must be set up so that the z -axis coincides with the axis of the cylinder. In this case $u = z$ and v is the angle from the x -axis in the xy plane. The local coordinates and normal vector are related to the u, v coordinates by

$$x = a \cos v$$

$$n_x = \cos v$$

$$y = a \sin v$$

$$n_y = \sin v$$

$$z = u$$

$$n_z = 0$$

elliptic_cylinder

elliptic cylindrical surface with axis along z -axis

Command: `elliptic_cylinder`, a , b

u_L , u_U , v_L , v_U

N_u , N_v , Q_u , Q_v

I_z , $[t_1, t_2, t_3]$

a Half the major diameter

b Half the minor diameter

u_L , u_U Lower and upper limits for the surface coordinate u

v_L , v_U Lower and upper limits for the surface coordinate v

N_u , N_v Number of subdivisions in the u and v directions in the planar rectangular region

Q_u , Q_v Number of Gaussian quadrature points per subarea in the u and v directions

I_z Specifies rotation from local to global coordinate system and orientation of normal

t_1 , t_2 , t_3 Components of the translation vector from the global origin to the local origin (default is $t_1 = t_2 = t_3 = 0$)

Surface definition:

The local coordinate system must be set up so that the axis of the cylinder coincides with the z -axis. In this case $u = z$ and v is related to the angle θ from the x -axis in the xy plane by

$$v = \tan^{-1} \left(\frac{a}{b} \tan \theta \right).$$

The local coordinates and normal vector are related to the u , v coordinates by

$$\begin{aligned} x &= a \cos v & n_x &= \frac{b \cos v}{\sqrt{a^2 - (a^2 - b^2) \cos^2 v}} \\ y &= b \sin v & n_y &= \frac{a \sin v}{\sqrt{a^2 - (a^2 - b^2) \cos^2 v}} \\ z &= u & n_z &= 0 \end{aligned}$$

Equal increments in v are not equal increments in θ , and vice versa. However, quadrants in the xy -plane do come out the same as shown in the following table:

v	x	y	θ
0	a	0	0
$\pi/2$	0	b	$\pi/2$
π	$-a$	0	π
$3\pi/2$	0	$-b$	$3\pi/2$

sphere

spherical surface

Command: **sphere, a**

u_L, u_U, v_L, v_U

N_u, N_v, Q_u, Q_v

$I_z, [t_1, t_2, t_3]$

a Radius of sphere

u_L, u_U Lower and upper limits for the surface coordinate u

v_L, v_U Lower and upper limits for the surface coordinate v

N_u, N_v Number of subdivisions in the u and v directions in the planar rectangular region

Q_u, Q_v Number of Gaussian quadrature points per subarea in the u and v directions

I_z Specifies rotation from local to global coordinate system and orientation of normal

t_1, t_2, t_3 Components of the translation vector from the global origin to the local origin (default is $t_1 = t_2 = t_3 = 0$)

Surface definition:

The local coordinate system must be set up so that the polar axis coincides with the z -axis. In this case u is the angle from the z -axis and v is the angle from the x -axis in the xy plane. The local coordinates and normal vector are related to the u, v coordinates by

$$x = a \sin u \cos v$$

$$y = a \sin u \sin v$$

$$z = a \cos u$$

$$n_x = \sin u \cos v$$

$$n_y = \sin u \sin v$$

$$n_z = \cos u$$

oblate_spheroid

oblate spheroidal surface obtained by rotating ellipse around minor axis

Command: **oblate_spheroid**, a , b

u_L , u_U , v_L , v_U

N_u , N_v , Q_u , Q_v

I_z , $[t_1, t_2, t_3]$

a	Half the major diameter of elliptical cross section
b	Half the minor diameter of elliptical cross section
u_L , u_U	Lower and upper limits for the surface coordinate u
v_L , v_U	Lower and upper limits for the surface coordinate v
N_u , N_v	Number of subdivisions in the u and v directions in the planar rectangular region
Q_u , Q_v	Number of Gaussian quadrature points per subarea in the u and v directions
I_z	Specifies rotation from local to global coordinate system and orientation of normal
t_1 , t_2 , t_3	Components of the translation vector from the global origin to the local origin (default is $t_1 = t_2 = t_3 = 0$)

Surface definition:

The local coordinate system must be set up so that the axis of rotation coincides with the z -axis. In this case v is the angle from the x -axis in the xy plane. u is related to the angle θ from the z -axis by

$$u = \tan^{-1} \left(\frac{b}{a} \tan \theta \right).$$

The local coordinates and normal vector are related to the u, v coordinates by

$$\begin{aligned}
 x &= a \sin u \cos v & n_x &= \frac{b \sin u \cos v}{\sqrt{a^2 - (a^2 - b^2) \cos^2 v}} \\
 y &= a \sin u \sin v & n_y &= \frac{b \sin u \sin v}{\sqrt{b^2 - (a^2 - b^2) \cos^2 u}} \\
 z &= b \cos u & n_z &= \frac{a \cos u}{\sqrt{b^2 - (a^2 - b^2) \cos^2 u}}
 \end{aligned}$$

Equal increments in u do not produce equal increments in θ , and vice versa. However, quadrants do come out the same as shown in the following table:

u	x	y	z	θ
0	0	0	b	0
$\pi/2$	$a \cos v$	$a \sin v$	0	$\pi/2$
π	0	0	$-b$	π

prolate_spheroid

prolate spheroidal surface obtained by rotating ellipse around major axis

Command: **prolate_spheroid**, a , b

u_L , u_U , v_L , v_U

N_u , N_v , Q_u , Q_v

I_z , $[t_1, t_2, t_3]$

a	Half the major diameter of elliptical cross section
b	Half the minor diameter of elliptical cross section
u_L , u_U	Lower and upper limits for the surface coordinate u
v_L , v_U	Lower and upper limits for the surface coordinate v
N_u , N_v	Number of subdivisions in the u and v directions in the planar rectangular region
Q_u , Q_v	Number of Gaussian quadrature points per subarea in the u and v directions
I_z	Specifies rotation from local to global coordinate system and orientation of normal
t_1 , t_2 , t_3	Components of the translation vector from the global origin to the local origin (default is $t_1 = t_2 = t_3 = 0$)

Surface definition:

The local coordinate system must be set up so that the axis of rotation coincides with the z -axis. In this case v is the angle from the x -axis in the xy plane and u is related to the angle θ from the z -axis by

$$u = \tan^{-1} \left(\frac{a}{b} \tan \theta \right).$$

The local coordinates and normal vector are related to the u, v coordinates by

$$\begin{aligned}
 x &= b \sin u \cos v & n_x &= \frac{a \sin u \cos v}{\sqrt{a^2 - (a^2 - b^2) \cos^2 v}} \\
 y &= b \sin u \sin v & n_y &= \frac{a \sin u \sin v}{\sqrt{b^2 - (a^2 - b^2) \cos^2 u}} \\
 z &= a \cos u & n_z &= \frac{b \cos u}{\sqrt{b^2 - (a^2 - b^2) \cos^2 u}}
 \end{aligned}$$

Equal increments in u are not equal increments in θ , and vice versa. However, quadrants do come out the same as shown in the following table:

u	x	y	z	θ
0	0	0	a	0
$\pi/2$	$b \cos v$	$b \sin v$	0	$\pi/2$
π	0	0	$-a$	π

fe_axisymmetric

curve generated by finite element interpolation functions is rotated around z -axis

Command: **fe_axisymmetric**, file.crd, file.elt, Q_u , Q_v
 I_z , $[t_1, t_2, t_3]$

file.crd File containing nodal coordinates. This file is an ASCII file containing three columns of data with one or more spaces between columns. The first column contains nodal numbers, the second column contains the radial r coordinates of the nodes, and the third column contains the axial z coordinates of the nodes. The nodes lie along the generating curve for the surface. This curve is rotated around the z -axis to generate the surface.

file.elt File containing element node numbers. This file is an ASCII file that contains two columns if linear interpolation is used and three columns if quadratic interpolation is used. The columns are separated by one or more spaces. Each line of data contains the node numbers for an element. If there are two columns, the node numbers are for the first and last node in the element. If there are three columns, then the columns correspond to first node, middle node, and last node respectively.

Q_u , Q_v Number of Gaussian quadrature points in the u and v directions

I_z Specifies rotation from local to global coordinate system and orientation of normal

t_1, t_2, t_3 Components of the translation vector from the global origin to the local origin (default is $t_1 = t_2 = t_3 = 0$)

Surface definition:

The local coordinate system is set up with the z -axis being the axis of rotation. Each finite element corresponds to one CHIEF subdivision of the surface. The surface coordinate v is the angle from the x -axis in the xy -plane. The surface coordinate u is in the interval $[-1,1]$. The local coordinates and normal vector are related to the u, v coordinates by

$$\begin{aligned} x &= r(u) \cos v & n_x &= n_r(u) \cos v \\ y &= r(u) \sin v & n_y &= n_r(u) \sin v \\ z &= z(u) & n_z &= n_z(u) \end{aligned}$$

where

$$\begin{pmatrix} r(u) \\ z(u) \end{pmatrix} = \sum_{n=1}^{2,3} \phi_n(u) \begin{pmatrix} r_n \\ z_n \end{pmatrix}$$

and

$$\begin{pmatrix} t_r(u) \\ t_z(u) \end{pmatrix} = \sum_{n=1}^{2,3} \phi'_n(u) \begin{pmatrix} r_n \\ z_n \end{pmatrix} \quad \text{tangent vector}$$

$$\begin{pmatrix} n_r(u) \\ n_z(u) \end{pmatrix} = \begin{pmatrix} -t_z(u)/\sqrt{t_r^2(u) + t_z^2(u)} \\ t_r(u)/\sqrt{t_r^2(u) + t_z^2(u)} \end{pmatrix}.$$

r_n, z_n given coordinates of nodes belonging to element

$\phi_n(u)$ finite element interpolation function (linear or quadratic)

For linear interpolation, the interpolation functions ϕ_n are given by

$$\begin{aligned} \phi_1(u) &= \frac{1}{2}(1 - u) \\ \phi_2(u) &= \frac{1}{2}(1 + u). \end{aligned}$$

For quadratic interpolation,

$$\begin{aligned} \phi_1(u) &= \frac{1}{2}u(u - 1) \\ \phi_2(u) &= 1 - u^2 \\ \phi_3(u) &= \frac{1}{2}u(u + 1). \end{aligned}$$

The normal has been chosen so that it points to the left as you travel along the cross-section curve.

fe_3d

surface generated by finite element interpolation functions

Command: **fe_3d**, file.crd, file.elt, Q_u , Q_v
 I_z , $[t_1, t_2, t_3]$

file.crd File containing nodal coordinates. This file is an ASCII file containing four columns of data with one or more spaces between columns. The first column contains nodal numbers and the second through fourth columns contain the x , y , z coordinates of the nodes.

file.elt File containing element node numbers. This file is an ASCII file that contains four columns if linear interpolation is used and eight columns if quadratic interpolation is used. The columns are separated by one or more spaces. Each line of data contains the node numbers for an element. If there are four columns, the node numbers are for the corner nodes of the element taken in a counterclockwise direction around the element. If there are eight columns, then the first four columns are the same as for the linear case and the last four columns are for the midnodes taken in a counterclockwise direction beginning with the node between the first and second nodes.

Q_u , Q_v Number of Gaussian quadrature points in the u and v directions

I_z Specifies rotation from local to global coordinate system and orientation of normal

t_1 , t_2 , t_3 Components of the translation vector from the global origin to the local origin (default is $t_1 = t_2 = t_3 = 0$)

Surface definition:

Each finite element corresponds to one CHIEF subdivision of the surface. Figure 5 shows the base rectangle in the uv coordinate system.

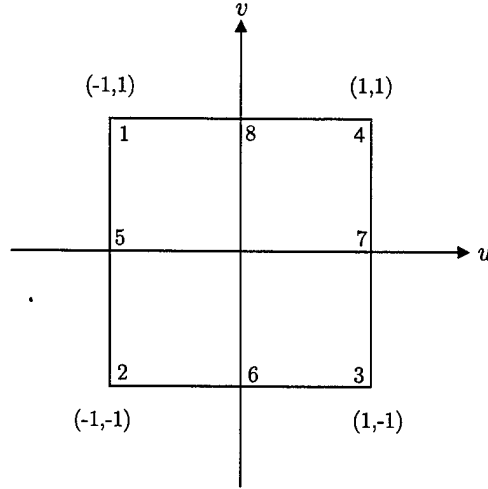


Figure 5. The base rectangle in the uv coordinate system.

The local coordinates and normal vector are related to the u, v coordinates by

$$\begin{aligned} x &= x(u, v) & n_x &= t_x(u, v) / \sqrt{t_x(u, v)^2 + t_y(u, v)^2 + t_z(u, v)^2} \\ y &= y(u, v) & n_y &= t_y(u, v) / \sqrt{t_x(u, v)^2 + t_y(u, v)^2 + t_z(u, v)^2} \\ z &= z(u, v) & n_z &= t_z(u, v) / \sqrt{t_x(u, v)^2 + t_y(u, v)^2 + t_z(u, v)^2}, \end{aligned}$$

where

$$\begin{pmatrix} x(u, v) \\ y(u, v) \\ z(u, v) \end{pmatrix} = \sum_{n=1}^{4,8} \phi_n(u, v) \begin{pmatrix} x_n \\ y_n \\ z_n \end{pmatrix}$$

and

$$\begin{pmatrix} t_x^u(u, v) \\ t_y^u(u, v) \\ t_z^u(u, v) \end{pmatrix} = \sum_{n=1}^{4,8} \frac{\partial \phi_n(u, v)}{\partial u} \begin{pmatrix} x_n \\ y_n \\ z_n \end{pmatrix} \quad u \text{ tangent vector}$$

$$\begin{pmatrix} t_x^v(u, v) \\ t_y^v(u, v) \\ t_z^v(u, v) \end{pmatrix} = \sum_{n=1}^{4,8} \frac{\partial \phi_n(u, v)}{\partial v} \begin{pmatrix} x_n \\ y_n \\ z_n \end{pmatrix} \quad v \text{ tangent vector}$$

$$\begin{pmatrix} t_x(u, v) \\ t_y(u, v) \\ t_z(u, v) \end{pmatrix} = \begin{pmatrix} t_y^u(u, v)t_z^v(u, v) - t_z^u(u, v)t_y^v(u, v) \\ t_z^u(u, v)t_x^v(u, v) - t_x^u(u, v)t_z^v(u, v) \\ t_x^u(u, v)t_y^v(u, v) - t_y^u(u, v)t_x^v(u, v) \end{pmatrix}$$

x_n, y_n, z_n given coordinates of nodes belonging to element

$\phi_n(u, v)$ finite element interpolation function (linear or quadratic)

For linear interpolation, the interpolation functions ϕ_n are given by

$$\begin{aligned} \phi_1(u, v) &= \frac{1}{4}(1-u)(1+v) \\ \phi_2(u, v) &= \frac{1}{4}(1-u)(1-v) \\ \phi_3(u, v) &= \frac{1}{4}(1+u)(1-v) \\ \phi_4(u, v) &= \frac{1}{4}(1+u)(1+v). \end{aligned}$$

For quadratic interpolation,

$$\begin{aligned} \phi_1(u, v) &= \frac{1}{4}(1-u)(1+v)(v-u-1) \\ \phi_2(u, v) &= \frac{1}{4}(1-u)(1-v)(-v-u-1) \\ \phi_3(u, v) &= \frac{1}{4}(1+u)(1-v)(-v+u-1) \\ \phi_4(u, v) &= \frac{1}{4}(1+u)(1+v)(v+u-1) \\ \phi_5(u, v) &= \frac{1}{2}(1-u)(1+v)(1-v) \\ \phi_6(u, v) &= \frac{1}{2}(1-u)(1-v)(1+u) \\ \phi_7(u, v) &= \frac{1}{2}(1+u)(1-v)(1+v) \\ \phi_8(u, v) &= \frac{1}{2}(1+u)(1+v)(1-u). \end{aligned}$$

The normal was chosen so that the nodes appear in counterclockwise order when viewed from the positive normal side of the surface.

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5. CONTROL SECTION

In this section, commands are given to specify the type of job CHIEF is asked to perform. The commands in this section may be given in any order. Only the first three characters of the command word itself are used by the program. Other forms of the command words are perfectly valid as long as the same first three characters are used.

Each command line consists of a command or a command followed by one or more arguments. Some command lines must be followed by additional lines of data. Commands, arguments, and data items are separated by commas. Parameters that have been defined in the parameter section and expressions involving these parameters may be used for any numerical input in this section. As always, blank lines, comments, and spaces are ignored.

The following types of problems may be run in CHIEF (with only one type allowed per run). The first two types are the most commonly used. Following each type are a list of commands that must be included in the input file. Optional commands are given in braces.

1. Calculate surface and/or field pressures (see example problems 1, 2, 5, 6, 8):

velocity or planewave

surface pressures

[far-field]

[near-field]

2. Calculate impedance and/or field matrices (see example problem 4):

impedance

[far-field]

[near-field]

3. Calculate A and B matrices (see example problem 9):

a_b matrices

One or more of the following are required:

[surface pressures]

[far-field]

[near-field]

4. Point source check on numerical accuracy (see example problem 3):

point source

CHIEF solves exterior radiation or scattering problems by default. If the **inside** command is given, CHIEF solves an interior problem. For interior problems, commands such as **far-field** and **infinite baffle** make no sense. We now provide the format for each command. Optional parts of the command line are in brackets.

a_b matrices

outputs the surface or field A and B matrices

Command: **a_b matrices**

When the **surface pressures** command is given, CHIEF produces a system of equations of the form $AP = BV + P_{inc}$, where P is the vector of surface pressures, V is the vector of surface normal velocities, and P_{inc} is the vector of incident surface pressures resulting from an incident plane wave specified by the user. When the **far-field pressures** command is given, CHIEF produces a set of equations of the form $P_{ff} = AP + BV$, where P_{ff} is the vector of far-field radiated pressures at prescribed angles. When the **near-field pressures** command is given, CHIEF produces a set of equations of the form $P_{nf} = AP + BV$, where P_{nf} is the vector of near-field pressures at prescribed locations.

A and B matrices may be output for any or all of the above three cases. These matrices are output to binary files with extensions **.abs**, **.abf**, and/or **.abn** if the commands **surface pressures**, **far-field pressures**, and/or **near-field pressures**, respectively, are in the CHIEF input file.

far-field

calculates far-field pressures or matrix

Command: **far-field**, N , Iprt
 $\theta_L^1, \theta_U^1, \theta_{inc}^1, \phi_L^1, \phi_U^1, \phi_{inc}^1$
 \vdots
 $\theta_L^N, \theta_U^N, \theta_{inc}^N, \phi_L^N, \phi_U^N, \phi_{inc}^N$

N Number of far-field data lines to follow command

Iprt Print flag. If $\text{Iprt}=1$, then far-field pressures are written to the standard output file (`<input filename>.out`). If $\text{Iprt}=2$, then the far-field pressures are written to an ASCII file (`<input filename>.ffp`) containing only far-field output. If $\text{Iprt}=3$, then the far-field pressures are written to both the standard output file and the far-field ASCII output file. If far-field matrices are computed, they are written to the binary file (`<input filename>.pmf`) regardless of the value of the print flag.

$\theta_L^k, \theta_U^k, \theta_{inc}^k$ Lower limit, upper limit, and increment in θ for k -th θ, ϕ range

$\phi_L^k, \phi_U^k, \phi_{inc}^k$ Lower limit, upper limit, and increment in ϕ for k -th θ, ϕ range

Each data line specifies a set of equally spaced ϕ 's and a set of equally spaced θ 's. The program performs far-field computations for all θ, ϕ pairs, where θ is taken from the set of equally spaced θ 's and ϕ is taken from the set of equally spaced ϕ 's. Each successive data line specifies another collection of θ, ϕ pairs for which far-field calculations are to be performed.

If the **Impedance** command is contained in the control section, then far-field matrices are computed. Each matrix row corresponds to a direction specified by a θ, ϕ pair, and each column corresponds to a surface subdivision. If G is the far-field matrix, then the vector of far-field pressures P_{ff} at the specified directions is related to the vector of surface normal velocities V by

$$P_{ff} = GV.$$

If a surface velocity distribution is specified by a **Velocity** command in the control section, then the far-field radiated pressures corresponding to the velocity distribution are computed instead of the far-field matrix. If an incident plane wave is specified through the **Plane wave** command, then the scattered far-field pressures are computed.

fluid

user specified fluid density and sound speed

Command: **fluid, ρ , c**

ρ Density of fluid

c Sound speed in fluid

If the **fluid** command is omitted, then the default values of $\rho = 1000$ and $c = 1500$ will be used. These values are fairly typical for water in mks units, but if a different fluid or a different set of units is used, then the appropriate values can be set with this command.

frequency

specifies frequency range for calculations

Command: **frequency**, f_L [, f_U , f_{inc}]

f_L Lower frequency limit for range of equally spaced frequencies

f_U Upper frequency limit for range of equally spaced frequencies

f_{inc} Frequency increment

If f_u and f_{inc} are missing, then only one frequency f_L will be used.

impedance

calculates impedance matrix

Command: `impedance, Isym, Iprt`

Isym If $Isym = 1$, then the velocity distribution has the same symmetry as the radiating surface. If $Isym = 0$, then CHIEF will not take advantage of velocity symmetry

Iprt Print flag. If $Iprt = 1$, then the impedance matrix will be output to the binary file `<input filename>.zmx`.

The impedance matrix Z is defined by

$$F = ZV,$$

where V is the vector of surface normal velocities on the CHIEF subdivisions and F is the vector of surface forces on the CHIEF subdivisions.

infinite baffle

specifies infinite rigid baffle

Command: **infinite baffle**

CHIEF treats the radiating surface as a planar region in an infinite rigid baffle. The surface definition must only consist of planar regions.

inside

specifies that an interior problem is to be solved

Command: **inside**

CHIEF solves an interior problem instead of an external problem. The positive normal direction is still taken as external to the surface.

interior points

adds equations corresponding to prescribed interior points to improve numerical stability of CHIEF equations at certain critical frequencies

Command: **interior points, N**

x_1, y_1, z_1

\vdots

x_N, y_N, z_N

N Number of interior points per symmetry block

x_k, y_k, z_k Global cartesian coordinates of k -th interior point where $k = 1, \dots, N$.

The CHIEF surface A matrix becomes ill-conditioned near certain critical frequencies corresponding to resonances of the interior problem with a zero surface pressure boundary condition. The addition of equations corresponding to interior points relieves this ill-conditioning if at least one of the points does not lie on a nodal surface for the interior mode corresponding to the critical frequency.

near-field

calculates near-field pressures or matrix

Command: **near-field**, N , Iprt

x_1, y_1, z_1

\vdots

x_N, y_N, z_N

N Number of near-field points

Iprt Print flag. If $\text{Iprt} = 1$, then near-field pressures are written to the standard output file (`<input filename>.out`). If $\text{Iprt} = 2$, then the near-field pressures are written to an ASCII file (`<input filename>.nfp`) containing only near-field output. If $\text{Iprt} = 3$, then the near-field pressures are written to both the standard output file and the near-field ASCII output file. If near-field matrices are computed, they are output to the binary file (`<input filename>.pmn`) regardless of the value of the print flag.

x_k, y_k, z_k Global cartesian coordinates of k -th near-field point at which near-field pressures are desired ($k = 1, \dots, N$).

If the **Impedance** command is contained in the control section, then near-field matrices are computed. Each row of this matrix corresponds to a near-field point and each column corresponds to a surface subdivision. If G is the near-field matrix, then the vector of near-field pressures P_{nf} at the specified points is related to the vector of surface normal velocities V by

$$P_{nf} = GV.$$

If a surface velocity distribution is specified by a **Velocity** command in the control section, then the near-field radiated pressures corresponding to the velocity distribution are computed instead of the far-field matrix. If an incident plane wave is specified through the **Plane wave** command, then the scattered near-field pressures are computed.

plane wave

specifies rigid scattering problem

Command: **plane wave**, $Isym$, P_{inc} , θ_{inc} , ϕ_{inc}

$Isym$ If $Isym = 1$, then the incident pressure field has the same symmetry as the radiating surface. If $Isym = 0$, then CHIEF will not take advantage of velocity symmetry

P_{inc} Amplitude of the incident plane wave

θ_{inc}, ϕ_{inc} Angles (in degrees) specifying the direction from which the plane wave is coming relative to the global coordinate axes. θ_{inc} is the angle from the x_3 -axis and ϕ_{inc} is the angle from the x_1 -axis in the x_1x_2 -plane.

Since CHIEF does not contain any structural capabilities, it can only compute rigid scattering.

point source

uses pressures from specified point sources to check the accuracy of CHIEF calculations

Command:	point source, Isym, N $x_1, y_1, z_1, W_1^{re}, W_1^{im}, I_1^{ext}$ \vdots $x_N, y_N, z_N, W_N^{re}, W_N^{im}, I_N^{ext}$
Isym	Isym = 1 specifies that the point source distribution has the same symmetry as the radiating surface. In this case, the point sources only need to be input for the first symmetry block
N	Number of point sources
x_k, y_k, z_k	Global cartesian coordinates of k -th point source
W_k^{re}, W_k^{im}	Real and imaginary parts of the weight for the k -th point source
I_k^{ext}	Flag that indicates whether the k -th point source is interior to ($I_k^{ext} = 0$) or exterior to ($I_k^{ext} = 1$) the radiating surface

The point source check uses analytic expressions to calculate surface velocities and incident surface pressures (for exterior point sources) due to the prescribed point sources assuming that the surface is an imaginary surface in the free field. The surface pressures are then calculated using the CHIEF equations

$$AP = BV + P^{inc}.$$

The surface pressures calculated using CHIEF can be compared to the pressures on the surface calculated using analytical expressions for point sources. This comparison can be used to determine the adequacy of the surface break-up into subareas, adequacy of interior points to remove ill-conditioning at critical frequencies, and errors due to improper input such as wrong directions for normal vectors. The location of the point sources should be selected to produce a velocity distribution that is as smooth as the expected velocity distribution. For thin bodies, the velocity due to an interior point source will vary very rapidly near the point source. Therefore, it may be necessary to use exterior point sources to obtain a velocity distribution with the desired smoothness.

rhs symmetry

specifies that the velocity (appearing on the right-hand side of the equation $Ap = Bv$) has the same symmetry as the surface

Command: `rhs`

surface pressures

specifies calculation of surface pressures

Command: **surface pressures, [Iprt]**

Iprt Print flag. If Iprt = 1, then surface pressures are written to the standard output file (<input filename>.out). If Iprt = 2, then the surface pressures are written to an ASCII file (<input filename>.sps) that only contains surface pressure output. If Iprt = 3, then the surface pressures are written to both the standard output file and the surface pressure ASCII output file.

velocity

specifies surface normal velocity input

Command: **velocity, <filename>**

<filename> Name of file containing surface normal velocity input. This file is an ASCII file containing five columns separated by one or more spaces. The first column is the velocity distribution number (i.e., the first velocity distribution will have a 1 in this column, the second a 2, etc.). The second column contains the symmetry block number. The third column contains the surface subdivision number. The fourth and fifth columns contain the real and imaginary parts of the normal velocity.

If the velocity has the same symmetry as the radiating surface, then only one symmetry block of the velocities needs to be input.

velocity (alternate form)

specifies surface normal velocity input by means of a loop

Command: $\text{vel}(i_1 : i_2 : i_3, j_1 : j_2 : j_3, k_1 : k_2 : k_3) = (x, y) \quad I = I_1, I_2, I_3$

I	loop index (does not have to be I —the name can be selected by the user). If no loop is desired the portion of the command beginning with “ $I =$ ” can be omitted.
I_1, I_2, I_3	I_1 is the starting index for the loop, I_2 is the ending index for the loop, and I_3 is the step size. These limits can be replaced by any expression involving previously defined parameters.
$i_1 : i_2 : i_3$	specifies a range for the surface subdivision number, where i_1 is the starting index, i_2 is the ending index, and i_3 is the step size. If i_3 is not present, it is set to 1. If i_2 and i_3 are not present, i_2 is set equal to i_1 . The colon is not necessary if the following index is not present (e.g., the range could be given by $i_1 : i_2$ or just i_1). The range limits can be replaced by any expression involving previously defined parameters and/or the index I .
$j_1 : j_2 : j_3$	specifies a range for the symmetry block number, where j_1 is the starting index, j_2 is the ending index, and j_3 is the step size. If j_3 is not present, it is set to 1. If j_2 and j_3 are not present, j_2 is set equal to j_1 . The colon is not necessary if the following index is not present (e.g., the range could be given by $j_1 : j_2$ or just j_1). The range limits can be replaced by any expression involving previously defined parameters and/or the index I .
$k_1 : k_2 : k_3$	specifies a range for the velocity distribution number, where k_1 is the starting index, k_2 is the ending index, and k_3 is the step size. If k_3 is not present, it is set to 1. If k_2 and k_3 are not present, k_2 is set equal to k_1 . The colon is not necessary if the following index is not present (e.g., the range could be given by $k_1 : k_2$ or just k_1). The range limits can be replaced by any expression involving previously defined parameters and/or the index I .
x, y	x is the real part of the velocity and y is the imaginary part of the velocity. If the imaginary part is zero, the user can use x in place of (x, y) . x and y can be replaced by any expression involving previously defined parameters and/or the index I .

If the velocity has the same symmetry as the radiating surface, then only one symmetry block of the velocities needs to be input.

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6. OUTPUT FILE FORMATS

In this section, we describe the formats of the various output files. The files that are likely to be small are written as formatted ASCII files. The files that are likely to be large are written as unformatted binary files. The version of this program for Windows 95/98[®] and Windows NT[®] machines was compiled using the Lahey Fortran 95 compiler. The version for the DEC Alpha OSF1 was compiled using the Digital Fortran 90 compiler. In both cases, the unformatted sequential binary files are divided into records that have a 4-byte integer prefix and suffix containing the number of bytes in the record (excluding prefix and suffix). Both also use IEEE little endian format for floating point reals and integers. The output at each frequency in a binary file begins with a standard header record containing the following 12 items:

1. Frequency
2. Fluid density
3. Fluid sound speed
4. Symmetry type ('ROT', 'REF', or 'NONE')
5. Number of symmetry blocks
6. Number of symmetry blocks output
7. Velocity symmetry flag(0 = no symmetry, 1 = same symmetry as surface)
8. Number of rows in *A* and *B* matrices (number of areas plus number of interior points)
9. Number of areas (i.e., total number of subdivisions for radiating surface)
10. Number of theta-phi field point pairs
11. Number of near-field points
12. Number of velocity distributions.

The formats of quantities in the various output files are described using Fortran type specifiers. For example, (F12.3) specifies a fixed point style real number with a total width of 12 and 3 digits to the right of the decimal point, (I5) specifies a five digit integer, and (E14.2) specifies an exponential style real number with a total width of 14 and 3 digits to the right of the decimal place. The total width includes any preliminary plus or minus sign, the decimal point, and the exponent (E±xx). We will now look at each file type individually.

Surface pressure file (.sps)

This is a formatted ASCII file. The first line contains the frequency with the format (F12.3). The following lines have the form,

$$i_{rhs} \quad i_{blk} \quad i \quad P_{real}(i) \quad P_{imag}(i) \quad area(i),$$

where i_{rhs} is an index running over the number of velocity distributions, i_{blk} is an index running over the number of symmetry blocks, i is an index running over the number of CHIEF subdivisions, $P_{real}(i)$ and P_{imag} are the real and imaginary parts of the surface pressure on the i -th subdivision, and $area(i)$ is the area of the i -th subdivision. The format for each of these lines is (3I5, 3E15.6). The index i varies the fastest, next is i_{blk} , and slowest is i_{rhs} . The above lines are repeated for each frequency.

Far-field pressure file (.ffp)

This is a formatted ASCII file. The first line contains the frequency with the format (F12.3). The following lines have the form,

$$i_{rhs} \quad \phi \quad \theta \quad P_{ff}^{real}(\phi, \theta) \quad P_{ff}^{imag}(\phi, \theta),$$

where i_{rhs} is an index running over the number of velocity distributions, ϕ and θ run over all θ - ϕ pairs, and $P_{ff}^{real}(\phi, \theta)$, $P_{ff}^{imag}(\phi, \theta)$ are the real and imaginary parts of the far-field pressure. The format for each of these lines is (I5, 2F10.2, 2E15.6). The above lines are repeated for each frequency.

Near-field pressure file (.nfp)

This is a formatted ASCII file. The first line contains the frequency with the format (F12.3). The following lines have the form,

$$i_{rhs} \quad x \quad y \quad z \quad P_{nf}^{real}(x, y, z) \quad P_{nf}^{imag}(x, y, z),$$

where i_{rhs} is an index running over the number of velocity distributions, x , y , and z run over all prescribed near-field points, and $P_{nf}^{real}(x, y, z)$, $P_{nf}^{imag}(x, y, z)$ are the real and imaginary parts of the near-field pressure. The format for each of these lines is (I5, 3E12.4, 2E15.6). The above lines are repeated for each frequency.

Impedance Matrix file (.zmx)

This is a binary file. The first record is the standard header record for the first frequency. The second record contains the surface areas of the CHIEF subdivisions. The next records contain the necessary symmetry blocks of the impedance matrix (one block if there is velocity

symmetry). For each successive frequency, there is a header record followed by the necessary blocks of the impedance matrix. The matrices are written out column by column.

Far-field Matrix file (.pmf)

This is a binary file. The first record is the standard header record for the first frequency. The second record contains the theta-phi pairs for the far-field directions. The next records contain the necessary symmetry blocks of the far-field matrix (one block if there is velocity symmetry). For each successive frequency, there is a header record followed by the necessary blocks of the far-field matrix. The matrices are written out column by column.

Near-field Matrix file (.pmn)

This is a binary file. The first record is the standard header record for the first frequency. The second record contains the coordinates for the near-field points. The next records contain the necessary symmetry blocks of the near-field matrix (one block if there is velocity symmetry). For each successive frequency, there is a header record followed by the necessary blocks of the near-field matrix. The matrices are written out column by column.

Surface A,B Matrices file (.abs)

This is a binary file. The first record is the standard header record for the first frequency. The second record contains the surface areas of the CHIEF subdivisions. The next records contain the necessary symmetry blocks of the A , B matrices (one block if there is velocity symmetry). For each symmetry block, the A matrix is output first to a record and the B matrix is output to the following record. For each successive frequency, there is a header record followed by the necessary blocks of the A , B matrices. The matrices are written out column by column.

Far-field A,B Matrices file (.abf)

This is a binary file. The first record is the standard header record for the first frequency. The second record contains the theta-phi pairs for the far-field directions. The next records contain the necessary symmetry blocks of the A , B matrices (one block if there is velocity symmetry). For each symmetry block, the A matrix is output first to a record and the B matrix is output to the following record. For each successive frequency, there is a header record followed by the necessary blocks of the A , B matrices. The matrices are written out column by column.

Near-field A,B Matrices file (.abn)

This is a binary file. The first record is the standard header record for the first frequency. The second record contains the coordinates for the near-field points. The next records contain the necessary symmetry blocks of the A , B matrices (one block if there is velocity symmetry). For each symmetry block, the A matrix is output first to a record and the B matrix is output to the following record. For each successive frequency, there is a header

record followed by the necessary blocks of the A , B matrices. The matrices are written out column by column.

7. EXAMPLE PROBLEMS

In this section, we will show how to set up the ASCII input files for eight example problems. Most of these examples are the same as those used in the original CHIEF manual. To gain maximum benefit from these example problems, the user should try to set up each of the input files without looking at the answers provided.

Example Problem 1

Figure 6 shows the geometry for the first problem. It consists of a free-flooded cylinder having an inner radius of 1.68 m, an outer radius of 2.04 m, and a height of 1.2 m. The normal velocity on the inner cylindrical surface is -1.029 m/sec, the normal velocity on the outer cylindrical surface is 0.971 m/sec, and the normal velocity on the top and bottom surfaces is 0.097 m/sec.

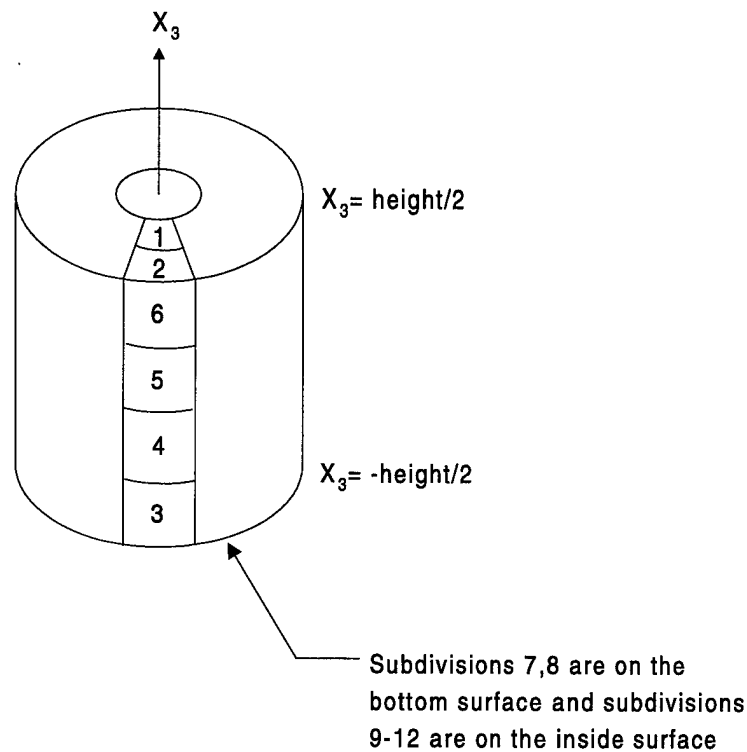


Figure 6. Geometry of example problem 1.

The problem is to compute the surface pressures and the far-field pattern in the plane $\phi = 0$ with $\Delta\theta = 5^\circ$ and $0 \leq \theta \leq 90^\circ$ for a frequency of $1500/(2\pi)$. Use 12-fold rotational symmetry and no velocity symmetry (even though there really is) to solve the problem. The surface and far-field pressures should be output to a file. The following is an input file for this problem:

```

freq1=1500/(2*pi)
nblks=12
ai=1.68
ao=2.04
ht=1.2
htd2=.5*ht
rotlim=pi/nblks
rho=999.89
end*params

rotational,nblks

circ_planar, htd2
ai,ao,-rotlim,rotlim
2,1,4,16
3,0,0,0

circ_cylinder, ao
-htd2,htd2,-rotlim,rotlim
4,1,4,16
3

circ_planar, -htd2
ai,ao,-rotlim,rotlim
2,1,4,16
-3

circ_cylinder, ai
-htd2,htd2,-rotlim,rotlim
4,1,4,16
-3

end*geom

fluid,rho,1500.05

freq, freq1, freq1, 0.

vel, tc1.vel

surface pressures,3

farfield pressures,1,3
0,90,5,0,0,0

```

The user also needs to construct a file containing the velocity distribution. Since we are not using the symmetry of the velocity, the velocity distribution must be input for all 12 of the rotational symmetry blocks. If we had chosen to use the velocity symmetry, then the input file would only need to contain the velocity distribution for the first symmetry block. The velocity input file for example problem 1 is shown below:

```

1 1 1    0.097  0
1 1 2    0.097  0
1 1 3    0.971  0
1 1 4    0.971  0
1 1 5    0.971  0
1 1 6    0.971  0
1 1 7    0.097  0
1 1 8    0.097  0
1 1 9   -1.029  0
1 1 10  -1.029  0
1 1 11  -1.029  0
1 1 12  -1.029  0
1 2 1    0.097  0
1 2 2    0.097  0
1 2 3    0.971  0
1 2 4    0.971  0
1 2 5    0.971  0
1 2 6    0.971  0
1 2 7    0.097  0
1 2 8    0.097  0
1 2 9   -1.029  0
1 2 10  -1.029  0
1 2 11  -1.029  0
1 2 12  -1.029  0
1 3 1    0.097  0
1 3 2    0.097  0
1 3 3    0.971  0
1 3 4    0.971  0
1 3 5    0.971  0
1 3 6    0.971  0
1 3 7    0.097  0
1 3 8    0.097  0
1 3 9   -1.029  0
1 3 10  -1.029  0
1 3 11  -1.029  0
1 3 12  -1.029  0
1 4 1    0.097  0
1 4 2    0.097  0

```

1 4 3	0.971	0
1 4 4	0.971	0
1 4 5	0.971	0
1 4 6	0.971	0
1 4 7	0.097	0
1 4 8	0.097	0
1 4 9	-1.029	0
1 4 10	-1.029	0
1 4 11	-1.029	0
1 4 12	-1.029	0
1 5 1	0.097	0
1 5 2	0.097	0
1 5 3	0.971	0
1 5 4	0.971	0
1 5 5	0.971	0
1 5 6	0.971	0
1 5 7	0.097	0
1 5 8	0.097	0
1 5 9	-1.029	0
1 5 10	-1.029	0
1 5 11	-1.029	0
1 5 12	-1.029	0
1 6 1	0.097	0
1 6 2	0.097	0
1 6 3	0.971	0
1 6 4	0.971	0
1 6 5	0.971	0
1 6 6	0.971	0
1 6 7	0.097	0
1 6 8	0.097	0
1 6 9	-1.029	0
1 6 10	-1.029	0
1 6 11	-1.029	0
1 6 12	-1.029	0
1 7 1	0.097	0
1 7 2	0.097	0
1 7 3	0.971	0
1 7 4	0.971	0
1 7 5	0.971	0
1 7 6	0.971	0
1 7 7	0.097	0
1 7 8	0.097	0
1 7 9	-1.029	0
1 7 10	-1.029	0
1 7 11	-1.029	0

1 7 12	-1.029	0
1 8 1	0.097	0
1 8 2	0.097	0
1 8 3	0.971	0
1 8 4	0.971	0
1 8 5	0.971	0
1 8 6	0.971	0
1 8 7	0.097	0
1 8 8	0.097	0
1 8 9	-1.029	0
1 8 10	-1.029	0
1 8 11	-1.029	0
1 8 12	-1.029	0
1 9 1	0.097	0
1 9 2	0.097	0
1 9 3	0.971	0
1 9 4	0.971	0
1 9 5	0.971	0
1 9 6	0.971	0
1 9 7	0.097	0
1 9 8	0.097	0
1 9 9	-1.029	0
1 9 10	-1.029	0
1 9 11	-1.029	0
1 9 12	-1.029	0
1 10 1	0.097	0
1 10 2	0.097	0
1 10 3	0.971	0
1 10 4	0.971	0
1 10 5	0.971	0
1 10 6	0.971	0
1 10 7	0.097	0
1 10 8	0.097	0
1 10 9	-1.029	0
1 10 10	-1.029	0
1 10 11	-1.029	0
1 10 12	-1.029	0
1 11 1	0.097	0
1 11 2	0.097	0
1 11 3	0.971	0
1 11 4	0.971	0
1 11 5	0.971	0
1 11 6	0.971	0
1 11 7	0.097	0
1 11 8	0.097	0

```

1 11 9 -1.029 0
1 11 10 -1.029 0
1 11 11 -1.029 0
1 11 12 -1.029 0
1 12 1 0.097 0
1 12 2 0.097 0
1 12 3 0.971 0
1 12 4 0.971 0
1 12 5 0.971 0
1 12 6 0.971 0
1 12 7 0.097 0
1 12 8 0.097 0
1 12 9 -1.029 0
1 12 10 -1.029 0
1 12 11 -1.029 0
1 12 12 -1.029 0

```

For this example, the velocity could be specified directly in the input file instead of reading the velocities from a data file. The line,

```
vel, tc1.vel
```

should be replaced by the lines,

```

vel(1:2,1:12,1)=(.097,0.)
vel(3:6,1:12,1)=(.971,0.)
vel(7:8,1:12,1)=(.097,0.)
vel(9:12,1:12,1)=(-1.029,0.)

```

The following pages show the output that would be obtained in the .out file for this problem.

REGION	NSEQNS	NSU	NSV	SUL	SUU	SVL	SVU	IORDRU	IORDRV
1	2	2	1	0.168000E+01	0.204000E+01	-.261799E+00	0.261799E+00	4	16
2	4	4	1	-.600000E+00	0.600000E+00	-.261799E+00	0.261799E+00	4	16
3	2	2	1	0.168000E+01	0.204000E+01	-.261799E+00	0.261799E+00	4	16
4	4	4	1	-.600000E+00	0.600000E+00	-.261799E+00	0.261799E+00	4	16

REGION - TRANSLATION (T1,T2,T3), IZAX

1	0.000000E+00	0.000000E+00	0.000000E+00	3
2	0.000000E+00	0.000000E+00	0.000000E+00	3
3	0.000000E+00	0.000000E+00	0.000000E+00	-3
4	0.000000E+00	0.000000E+00	0.000000E+00	-3

REGION - CCS

1	0.6000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	0.2040E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
3	-.6000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
4	0.1680E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

NO. OF SURFACE AREAS = 12 NO. OF SURFACE FIELD POINTS = 12

FREQUENCY= 238.7 RHO= 999.9 C= 1500.1

SYMMETRY TYPE= ROT NO. OF BLOCKS= 12

SURFACE PRESSURES (BLK#, AREA#, REAL, IMAG, MAG, ANG)

1	1	-0.724290E+06	0.223636E+06	0.758029E+06	162.84
1	2	-0.371080E+06	0.523689E+06	0.641833E+06	125.32
1	3	0.213456E+06	0.131391E+07	0.133114E+07	80.77
1	4	0.345704E+06	0.154564E+07	0.158383E+07	77.39
1	5	0.345704E+06	0.154564E+07	0.158383E+07	77.39
1	6	0.213456E+06	0.131391E+07	0.133114E+07	80.77
1	7	-0.724290E+06	0.223636E+06	0.758029E+06	162.84
1	8	-0.371080E+06	0.523689E+06	0.641834E+06	125.32
1	9	-0.162378E+07	-0.103560E+07	0.192591E+07	-147.47
1	10	-0.189947E+07	-0.144823E+07	0.238859E+07	-142.68
1	11	-0.189947E+07	-0.144823E+07	0.238859E+07	-142.68
1	12	-0.162378E+07	-0.103560E+07	0.192591E+07	-147.47
2	1	-0.724290E+06	0.223636E+06	0.758030E+06	162.84
2	2	-0.371080E+06	0.523689E+06	0.641834E+06	125.32
2	3	0.213456E+06	0.131391E+07	0.133114E+07	80.77
2	4	0.345704E+06	0.154564E+07	0.158383E+07	77.39
2	5	0.345704E+06	0.154564E+07	0.158383E+07	77.39
2	6	0.213456E+06	0.131391E+07	0.133114E+07	80.77
2	7	-0.724290E+06	0.223636E+06	0.758029E+06	162.84
2	8	-0.371079E+06	0.523689E+06	0.641834E+06	125.32
2	9	-0.162378E+07	-0.103560E+07	0.192591E+07	-147.47

2	10	-0.189947E+07	-0.144824E+07	0.238859E+07	-142.68
2	11	-0.189947E+07	-0.144824E+07	0.238859E+07	-142.68
2	12	-0.162378E+07	-0.103561E+07	0.192591E+07	-147.47
3	1	-0.724290E+06	0.223636E+06	0.758030E+06	162.84
3	2	-0.371079E+06	0.523689E+06	0.641834E+06	125.32
3	3	0.213456E+06	0.131391E+07	0.133114E+07	80.77
3	4	0.345705E+06	0.154564E+07	0.158383E+07	77.39
3	5	0.345705E+06	0.154564E+07	0.158383E+07	77.39
3	6	0.213456E+06	0.131391E+07	0.133114E+07	80.77
3	7	-0.724290E+06	0.223636E+06	0.758029E+06	162.84
3	8	-0.371079E+06	0.523689E+06	0.641834E+06	125.32
3	9	-0.162378E+07	-0.103561E+07	0.192591E+07	-147.47
3	10	-0.189947E+07	-0.144824E+07	0.238859E+07	-142.68
3	11	-0.189947E+07	-0.144824E+07	0.238859E+07	-142.68
3	12	-0.162378E+07	-0.103561E+07	0.192591E+07	-147.47
4	1	-0.724290E+06	0.223636E+06	0.758029E+06	162.84
4	2	-0.371079E+06	0.523689E+06	0.641834E+06	125.32
4	3	0.213456E+06	0.131391E+07	0.133114E+07	80.77
4	4	0.345704E+06	0.154564E+07	0.158383E+07	77.39
4	5	0.345704E+06	0.154564E+07	0.158383E+07	77.39
4	6	0.213456E+06	0.131391E+07	0.133114E+07	80.77
4	7	-0.724290E+06	0.223636E+06	0.758029E+06	162.84
4	8	-0.371079E+06	0.523689E+06	0.641834E+06	125.32
4	9	-0.162378E+07	-0.103561E+07	0.192591E+07	-147.47
4	10	-0.189947E+07	-0.144824E+07	0.238859E+07	-142.68
4	11	-0.189947E+07	-0.144824E+07	0.238859E+07	-142.68
4	12	-0.162378E+07	-0.103561E+07	0.192591E+07	-147.47
5	1	-0.724290E+06	0.223636E+06	0.758029E+06	162.84
5	2	-0.371079E+06	0.523689E+06	0.641833E+06	125.32
5	3	0.213456E+06	0.131391E+07	0.133114E+07	80.77
5	4	0.345704E+06	0.154564E+07	0.158383E+07	77.39
5	5	0.345704E+06	0.154564E+07	0.158383E+07	77.39
5	6	0.213456E+06	0.131391E+07	0.133114E+07	80.77
5	7	-0.724290E+06	0.223636E+06	0.758029E+06	162.84
5	8	-0.371079E+06	0.523689E+06	0.641834E+06	125.32
5	9	-0.162378E+07	-0.103561E+07	0.192591E+07	-147.47
5	10	-0.189947E+07	-0.144824E+07	0.238859E+07	-142.68
5	11	-0.189947E+07	-0.144824E+07	0.238859E+07	-142.68
5	12	-0.162378E+07	-0.103561E+07	0.192591E+07	-147.47
6	1	-0.724290E+06	0.223636E+06	0.758029E+06	162.84
6	2	-0.371079E+06	0.523689E+06	0.641833E+06	125.32
6	3	0.213456E+06	0.131391E+07	0.133114E+07	80.77
6	4	0.345705E+06	0.154564E+07	0.158383E+07	77.39
6	5	0.345705E+06	0.154564E+07	0.158383E+07	77.39
6	6	0.213456E+06	0.131391E+07	0.133114E+07	80.77
6	7	-0.724290E+06	0.223636E+06	0.758029E+06	162.84
6	8	-0.371079E+06	0.523689E+06	0.641834E+06	125.32
6	9	-0.162378E+07	-0.103561E+07	0.192591E+07	-147.47
6	10	-0.189947E+07	-0.144824E+07	0.238859E+07	-142.68

6	11	-0.189947E+07	-0.144824E+07	0.238859E+07	-142.68
6	12	-0.162378E+07	-0.103561E+07	0.192591E+07	-147.47
7	1	-0.724290E+06	0.223635E+06	0.758029E+06	162.84
7	2	-0.371079E+06	0.523689E+06	0.641834E+06	125.32
7	3	0.213456E+06	0.131391E+07	0.133114E+07	80.77
7	4	0.345704E+06	0.154564E+07	0.158383E+07	77.39
7	5	0.345704E+06	0.154564E+07	0.158383E+07	77.39
7	6	0.213456E+06	0.131391E+07	0.133114E+07	80.77
7	7	-0.724290E+06	0.223635E+06	0.758029E+06	162.84
7	8	-0.371079E+06	0.523689E+06	0.641834E+06	125.32
7	9	-0.162378E+07	-0.103561E+07	0.192591E+07	-147.47
7	10	-0.189947E+07	-0.144824E+07	0.238859E+07	-142.68
7	11	-0.189947E+07	-0.144824E+07	0.238859E+07	-142.68
7	12	-0.162378E+07	-0.103561E+07	0.192591E+07	-147.47
8	1	-0.724290E+06	0.223635E+06	0.758029E+06	162.84
8	2	-0.371079E+06	0.523689E+06	0.641833E+06	125.32
8	3	0.213456E+06	0.131391E+07	0.133114E+07	80.77
8	4	0.345705E+06	0.154564E+07	0.158383E+07	77.39
8	5	0.345705E+06	0.154564E+07	0.158383E+07	77.39
8	6	0.213456E+06	0.131391E+07	0.133114E+07	80.77
8	7	-0.724290E+06	0.223635E+06	0.758029E+06	162.84
8	8	-0.371079E+06	0.523689E+06	0.641834E+06	125.32
8	9	-0.162378E+07	-0.103561E+07	0.192591E+07	-147.47
8	10	-0.189947E+07	-0.144824E+07	0.238859E+07	-142.68
8	11	-0.189947E+07	-0.144824E+07	0.238859E+07	-142.68
8	12	-0.162378E+07	-0.103561E+07	0.192591E+07	-147.47
9	1	-0.724290E+06	0.223635E+06	0.758029E+06	162.84
9	2	-0.371079E+06	0.523689E+06	0.641833E+06	125.32
9	3	0.213456E+06	0.131391E+07	0.133114E+07	80.77
9	4	0.345704E+06	0.154564E+07	0.158383E+07	77.39
9	5	0.345704E+06	0.154564E+07	0.158383E+07	77.39
9	6	0.213456E+06	0.131391E+07	0.133114E+07	80.77
9	7	-0.724290E+06	0.223635E+06	0.758029E+06	162.84
9	8	-0.371079E+06	0.523689E+06	0.641833E+06	125.32
9	9	-0.162378E+07	-0.103561E+07	0.192591E+07	-147.47
9	10	-0.189947E+07	-0.144824E+07	0.238859E+07	-142.68
9	11	-0.189947E+07	-0.144824E+07	0.238859E+07	-142.68
9	12	-0.162378E+07	-0.103561E+07	0.192591E+07	-147.47
10	1	-0.724290E+06	0.223635E+06	0.758029E+06	162.84
10	2	-0.371079E+06	0.523689E+06	0.641834E+06	125.32
10	3	0.213456E+06	0.131391E+07	0.133114E+07	80.77
10	4	0.345704E+06	0.154564E+07	0.158383E+07	77.39
10	5	0.345704E+06	0.154564E+07	0.158383E+07	77.39
10	6	0.213456E+06	0.131391E+07	0.133114E+07	80.77
10	7	-0.724290E+06	0.223635E+06	0.758029E+06	162.84
10	8	-0.371079E+06	0.523689E+06	0.641834E+06	125.32
10	9	-0.162378E+07	-0.103561E+07	0.192591E+07	-147.47
10	10	-0.189947E+07	-0.144824E+07	0.238859E+07	-142.68
10	11	-0.189947E+07	-0.144824E+07	0.238859E+07	-142.68

10	12	-0.162378E+07	-0.103561E+07	0.192591E+07	-147.47
11	1	-0.724290E+06	0.223636E+06	0.758030E+06	162.84
11	2	-0.371079E+06	0.523689E+06	0.641834E+06	125.32
11	3	0.213456E+06	0.131391E+07	0.133114E+07	80.77
11	4	0.345705E+06	0.154564E+07	0.158383E+07	77.39
11	5	0.345705E+06	0.154564E+07	0.158383E+07	77.39
11	6	0.213456E+06	0.131391E+07	0.133114E+07	80.77
11	7	-0.724290E+06	0.223636E+06	0.758029E+06	162.84
11	8	-0.371079E+06	0.523689E+06	0.641834E+06	125.32
11	9	-0.162378E+07	-0.103561E+07	0.192591E+07	-147.47
11	10	-0.189947E+07	-0.144824E+07	0.238859E+07	-142.68
11	11	-0.189947E+07	-0.144824E+07	0.238859E+07	-142.68
11	12	-0.162378E+07	-0.103561E+07	0.192591E+07	-147.47
12	1	-0.724290E+06	0.223636E+06	0.758030E+06	162.84
12	2	-0.371080E+06	0.523689E+06	0.641834E+06	125.32
12	3	0.213456E+06	0.131391E+07	0.133114E+07	80.77
12	4	0.345704E+06	0.154564E+07	0.158383E+07	77.39
12	5	0.345704E+06	0.154564E+07	0.158383E+07	77.39
12	6	0.213456E+06	0.131391E+07	0.133114E+07	80.77
12	7	-0.724290E+06	0.223636E+06	0.758029E+06	162.84
12	8	-0.371079E+06	0.523689E+06	0.641834E+06	125.32
12	9	-0.162378E+07	-0.103560E+07	0.192591E+07	-147.47
12	10	-0.189947E+07	-0.144824E+07	0.238859E+07	-142.68
12	11	-0.189947E+07	-0.144824E+07	0.238859E+07	-142.68
12	12	-0.162378E+07	-0.103561E+07	0.192591E+07	-147.47

POWER OUT (KW)= 26697.008

CPOWER OUT = 0.266970E+08 0.378524E+08

FREQUENCY= 238.7 RHO= 999.9 C= 1500.1

SYMMETRY TYPE= ROT NO. OF BLOCKS= 12

FAR-FIELD PRESSURES (PHI, THETA, FFP (RL, IM, MAG, ANG) , NORMALIZED PATTERN, SOURCE LEVEL, DI)

0.00	0.00	0.203828E+06	0.149904E+06	0.253016E+06	36.33	-19.25
0.00	5.00	0.187885E+06	0.125888E+06	0.226161E+06	33.82	-20.23
0.00	10.00	0.141056E+06	0.553569E+05	0.151530E+06	21.43	-23.71
0.00	15.00	0.662310E+05	-572915E+05	0.875720E+05	-40.86	-28.47
0.00	20.00	-321061E+05	-205238E+06	0.207734E+06	-98.89	-20.97
0.00	25.00	-148321E+06	-379923E+06	0.407848E+06	-111.33	-15.11
0.00	30.00	-276163E+06	-571862E+06	0.635053E+06	-115.78	-11.26
0.00	35.00	-409313E+06	-771487E+06	0.873343E+06	-117.95	-8.49
0.00	40.00	-541879E+06	-969895E+06	0.111100E+07	-119.19	-6.40
0.00	45.00	-668782E+06	-115945E+07	0.133850E+07	-119.98	-4.78

0.00	50.00	-.786008E+06	-.133414E+07	0.154847E+07	-120.50	-3.52
0.00	55.00	-.890704E+06	-.148977E+07	0.173573E+07	-120.87	-2.53
0.00	60.00	-.981145E+06	-.162382E+07	0.189722E+07	-121.14	-1.75
0.00	65.00	-.105658E+07	-.173530E+07	0.203165E+07	-121.34	-1.16
0.00	70.00	-.111699E+07	-.182432E+07	0.213912E+07	-121.48	-0.71
0.00	75.00	-.116287E+07	-.189174E+07	0.222057E+07	-121.58	-0.39
0.00	80.00	-.119492E+07	-.193871E+07	0.227738E+07	-121.65	-0.17
0.00	85.00	-.121382E+07	-.196637E+07	0.231083E+07	-121.69	-0.04
0.00	90.00	-.122006E+07	-.197549E+07	0.232188E+07	-121.70	0.00 *
				247.3		2.28

* DIRECTION FOR PATTERN NORMALIZATION

Example Problem 2

Figure 7 shows the geometry for the second problem. The geometry of this problem is the same as example problem 1. In this example, three planes of reflective symmetry are used in place of rotational symmetry and velocity symmetry is used. The surface and far-field pressures should be output to a file.

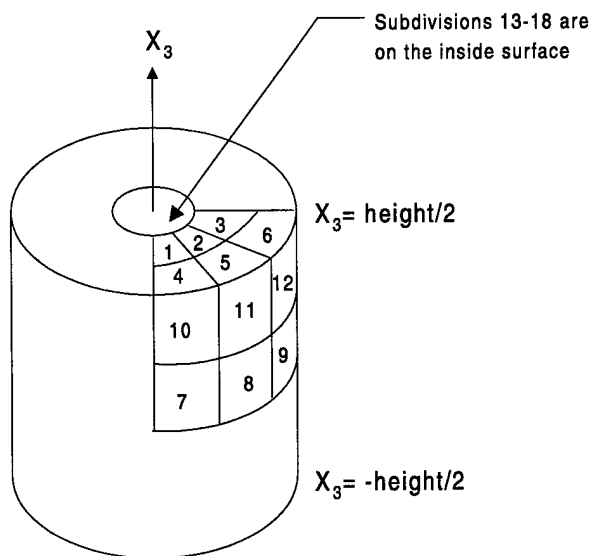


Figure 7. Geometry of example problem 2.

The following is an input file for this problem:

```
freq1=1500/(2*pi)
ai=1.68
ao=2.04
ht=1.2
htd2=.5*ht
reflim=pi/2
end*params

reflective,3

circ_planar, htd2
ai,ao,0,reflim
2,3,4,16
3,0,0,0

circ_cylinder, ao
0,htd2,0,reflim
2,3,4,16
3
```

```

circ_cylinder, ai
0,htd2,0,reflim
2,3,4,16
-3

end*geom

freq, freq1, freq1, 0.

rhs symmetry

vel, tc2.vel

surface pressures,3

farfield pressures,1,3
0,90,5,0,0,0

```

The user also needs to construct a file containing the velocity distribution. Since we chose to use the velocity symmetry, the input file only needs to contain the velocity distribution for the first octant. The velocity input file for example problem 2 is shown below:

```

1 1 1 0.097 0
1 1 2 0.097 0
1 1 3 0.097 0
1 1 4 0.097 0
1 1 5 0.097 0
1 1 6 0.097 0
1 1 7 0.971 0
1 1 8 0.971 0
1 1 9 0.971 0
1 1 10 0.971 0
1 1 11 0.971 0
1 1 12 0.971 0
1 1 13 -1.029 0
1 1 14 -1.029 0
1 1 15 -1.029 0
1 1 16 -1.029 0
1 1 17 -1.029 0
1 1 18 -1.029 0

```

As in example problem 1, the command

```
vel, tc2.vel
```

and the velocity input file can be replaced by the lines,

```
vel(1:2,1,1)=(.097,0.)  
vel(3:6,1,1)=(.971,0.)  
vel(7:8,1,1)=(.097,0.)  
vel(9:12,1,1)=(-1.029,0.)
```

The following pages show the output that would be obtained in the .out file for this problem.

REGION	NSEQNS	NSU	NSV	SUL	SUU	SVL	SVU	IORDRU	IORDRV
1	2	2	3	0.168000E+01	0.204000E+01	0.000000E+00	0.157080E+01	4	16
2	4	2	3	0.000000E+00	0.600000E+00	0.000000E+00	0.157080E+01	4	16
3	4	2	3	0.000000E+00	0.600000E+00	0.000000E+00	0.157080E+01	4	16

REGION - TRANSLATION (T1,T2,T3), IZAX

1	0.000000E+00	0.000000E+00	0.000000E+00	3
2	0.000000E+00	0.000000E+00	0.000000E+00	3
3	0.000000E+00	0.000000E+00	0.000000E+00	-3

REGION - CCS

1	0.6000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	0.2040E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
3	0.1680E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

NO. OF SURFACE AREAS = 18 NO. OF SURFACE FIELD POINTS = 18

FREQUENCY= 238.7 RHO= 1000.0 C= 1500.0

SYMMETRY TYPE= REF NO. OF BLOCKS= 8

SURFACE PRESSURES (BLX#,AREA#, REAL,IMAG,MAG,ANG)

1	1	-0.724309E+06	0.223841E+06	0.758108E+06	162.83
1	2	-0.724322E+06	0.223837E+06	0.758119E+06	162.83
1	3	-0.724313E+06	0.223840E+06	0.758112E+06	162.83
1	4	-0.371020E+06	0.523866E+06	0.641944E+06	125.31
1	5	-0.371026E+06	0.523870E+06	0.641951E+06	125.31
1	6	-0.371023E+06	0.523867E+06	0.641946E+06	125.31
1	7	0.345970E+06	0.154586E+07	0.158410E+07	77.38
1	8	0.345947E+06	0.154582E+07	0.158406E+07	77.39
1	9	0.345961E+06	0.154586E+07	0.158410E+07	77.39
1	10	0.213674E+06	0.131412E+07	0.133137E+07	80.76
1	11	0.213657E+06	0.131408E+07	0.133134E+07	80.77
1	12	0.213667E+06	0.131411E+07	0.133137E+07	80.76
1	13	-0.189996E+07	-0.144817E+07	0.238894E+07	-142.68
1	14	-0.189991E+07	-0.144812E+07	0.238888E+07	-142.69
1	15	-0.189995E+07	-0.144816E+07	0.238892E+07	-142.69
1	16	-0.162417E+07	-0.103550E+07	0.192619E+07	-147.48
1	17	-0.162413E+07	-0.103547E+07	0.192614E+07	-147.48
1	18	-0.162416E+07	-0.103549E+07	0.192617E+07	-147.48

*** FULL VELOCITY SYMMETRY ***

POWER OUT (KW)= 26705.986

CPower OUT = 0.267060E+08 0.378542E+08

FREQUENCY= 238.7 RHO= 1000.0 C= 1500.0

SYMMETRY TYPE= REF NO. OF BLOCKS= 8

FAR-FIELD PRESSURES (PHI, THETA, FFP(RL, IM, MAG, ANG) ,										NORMALIZED PATTERN, SOURCE LEVEL, DI)	
0.00	0.00	0.203834E+06	0.149854E+06	0.252991E+06	0.252991E+06	36.32	-19.26				
0.00	5.00	0.187886E+06	0.125835E+06	0.226132E+06	0.226132E+06	33.81	-20.23				
0.00	10.00	0.141040E+06	0.552974E+05	0.151493E+06	0.151493E+06	21.41	-23.71				
0.00	15.00	0.661884E+05	-573615E+05	0.875856E+05	0.875856E+05	-40.91	-28.47				
0.00	20.00	-321831E+05	-205321E+06	0.207828E+06	0.207828E+06	-98.91	-20.96				
0.00	25.00	-148438E+06	-380021E+06	0.407983E+06	0.407983E+06	-111.34	-15.11				
0.00	30.00	-276324E+06	-571977E+06	0.635226E+06	0.635226E+06	-115.79	-11.26				
0.00	35.00	-409319E+06	-771617E+06	0.873555E+06	0.873555E+06	-117.96	-8.49				
0.00	40.00	-542129E+06	-970040E+06	0.111125E+07	0.111125E+07	-119.20	-6.40				
0.00	45.00	-669074E+06	-115960E+07	0.133878E+07	0.133878E+07	-119.98	-4.78				
0.00	50.00	-786337E+06	-133431E+07	0.154878E+07	0.154878E+07	-120.51	-3.52				
0.00	55.00	-891065E+06	-148994E+07	0.173607E+07	0.173607E+07	-120.88	-2.53				
0.00	60.00	-981533E+06	-162400E+07	0.189757E+07	0.189757E+07	-121.15	-1.75				
0.00	65.00	-105699E+07	-173548E+07	0.203202E+07	0.203202E+07	-121.34	-1.16				
0.00	70.00	-111742E+07	-182451E+07	0.213950E+07	0.213950E+07	-121.49	-0.71				
0.00	75.00	-116331E+07	-189192E+07	0.222096E+07	0.222096E+07	-121.59	-0.39				
0.00	80.00	-119537E+07	-193890E+07	0.227777E+07	0.227777E+07	-121.65	-0.17				
0.00	85.00	-121427E+07	-196655E+07	0.231123E+07	0.231123E+07	-121.69	-0.04				
0.00	90.00	-122052E+07	-197567E+07	0.232227E+07	0.232227E+07	-121.71	0.00				
								247.3		2.28	

* DIRECTION FOR PATTERN NORMALIZATION

Example Problem 3

The geometry for this problem is the same as for example problem 1. This example illustrates the use of a point source check. A point source check can be used to determine the adequacy of the surface discretization as well as the need for and the placement of interior points. The basic idea of a point source check is to consider the boundary surface as an imaginary surface in an infinite fluid medium containing a finite number of point sources. The surface pressures are calculated using the CHIEF formulation with a surface velocity distribution produced by the point sources and compared with the exact pressures due to the point sources. If the point sources are inside the body, then the CHIEF computation is like a radiation problem. If the point sources are outside the body, then the CHIEF computation is like a scattering problem. For this example, we will use one point source located at the origin, having a complex weight of $1+i0$. (This point is outside the body.) For thin bodies like this free-flooded cylinder, it is usually better to place the point source outside the body, since point sources inside the body are so close to the surface that they will produce a surface velocity distribution that varies more rapidly than the ones likely to be used in practice. The input file for this example is shown below:

```
freq1=1500/(2*pi)
nblks=12
ai=1.68
ao=2.04
ht=1.2
htd2=.5*ht
rotlim=pi/nblks
end*params

rotational,nblks

circ_planar, htd2
ai,ao,-rotlim,rotlim
2,1,4,16
3,0,0,0

circ_cylinder, ao
-htd2,htd2,-rotlim,rotlim
4,1,4,16
3,0,0,0

circ_planar, -htd2
ai,ao,-rotlim,rotlim
2,1,4,16
-3,0,0,0

circ_cylinder, ai
```

```
-htd2,htd2,-rotlim,rotlim  
4,1,4,16  
-3,0,0,0
```

```
end*geom
```

```
freq, freq1, freq1, 0.  
point source check, 1,1  
0,0,0,1,0,1
```

The following pages show the output that would be obtained in the .out file for this problem.

REGION	NSEQNS	NSU	NSV	SUL	SUU	SVL	SVU	IORDRU	IORDRV
1	2	2	1	0.168000E+01	0.204000E+01	-.261799E+00	0.261799E+00	4	16
2	4	4	1	-.600000E+00	0.600000E+00	-.261799E+00	0.261799E+00	4	16
3	2	2	1	0.168000E+01	0.204000E+01	-.261799E+00	0.261799E+00	4	16
4	4	4	1	-.600000E+00	0.600000E+00	-.261799E+00	0.261799E+00	4	16

REGION - TRANSLATION (T1,T2,T3), IZAX

1	0.000000E+00	0.000000E+00	0.000000E+00	3
2	0.000000E+00	0.000000E+00	0.000000E+00	3
3	0.000000E+00	0.000000E+00	0.000000E+00	-3
4	0.000000E+00	0.000000E+00	0.000000E+00	-3

REGION - CCS

1	0.6000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	0.2040E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
3	-.6000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
4	0.1680E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

NO. OF SURFACE AREAS = 12 NO. OF SURFACE FIELD POINTS = 12

FREQUENCY= 238.7 RHO= 1000.0 C= 1500.0

SYMMETRY TYPE= ROT NO. OF BLOCKS= 12

POINT SOURCES (X,Y,Z), IOPTSC, WEIGHT

1	0.0000E+00	0.0000E+00	0.0000E+00	1	0.1000E+010.0000E+00
---	------------	------------	------------	---	----------------------

VELOCITIES (BLK#,AREA#, REAL,IMAG,MAG,ANG)

1	1	-0.164642E+01	0.165978E+01	0.233785E+01	134.77
1	2	-0.115909E+01	0.153859E+01	0.192633E+01	126.99
1	3	-0.354272E+01	0.511123E+01	0.621896E+01	124.73
1	4	-0.389640E+01	0.521826E+01	0.651246E+01	126.75
1	5	-0.389640E+01	0.521826E+01	0.651246E+01	126.75
1	6	-0.354272E+01	0.511123E+01	0.621896E+01	124.73
1	7	-0.164642E+01	0.165978E+01	0.233785E+01	134.77
1	8	-0.115909E+01	0.153859E+01	0.192633E+01	126.99
1	9	0.592801E+01	-0.489498E+01	0.768779E+01	-39.55
1	10	0.655304E+01	-0.499256E+01	0.823820E+01	-37.30
1	11	0.655304E+01	-0.499256E+01	0.823820E+01	-37.30
1	12	0.592801E+01	-0.489498E+01	0.768779E+01	-39.55

*** FULL VELOCITY SYMMETRY ***

FREQUENCY= 238.7 RHO= 1000.0 C= 1500.0

SYMMETRY TYPE= ROT NO. OF BLOCKS= 12

POINT SOURCES (X,Y,Z), IOPTSC, WEIGHT

1 0.0000E+00 0.0000E+00 0.0000E+00 1 0.1000E+010.0000E+00

SURFACE PRESSURES (BLK#,AREA#, SP(R,I),PSP(R,I),

%ERROR(R,I,M),ERROR ANGLE)

1	1	-0.915728E+07	0.300122E+07	-0.920631E+07	0.282903E+07	0.53	6.09	0.06	1.06
1	2	-0.782905E+07	0.410708E+07	-0.786823E+07	0.399109E+07	0.50	2.91	0.21	0.79
1	3	-0.739761E+07	0.430778E+07	-0.748496E+07	0.426819E+07	1.17	0.93	0.65	0.52
1	4	-0.776209E+07	0.404178E+07	-0.782674E+07	0.402221E+07	0.83	0.49	0.55	0.31
1	5	-0.776209E+07	0.404178E+07	-0.782674E+07	0.402221E+07	0.83	0.49	0.55	0.31
1	6	-0.739761E+07	0.430778E+07	-0.748496E+07	0.426819E+07	1.17	0.93	0.65	0.52
1	7	-0.915728E+07	0.300122E+07	-0.920631E+07	0.282903E+07	0.53	6.09	0.06	1.06
1	8	-0.782905E+07	0.410708E+07	-0.786823E+07	0.399109E+07	0.50	2.91	0.21	0.79
1	9	-0.103701E+08	0.171495E+07	-0.102030E+08	0.173490E+07	1.64	1.15	1.56	0.26
1	10	-0.107577E+08	0.124760E+07	-0.106003E+08	0.123396E+07	1.49	1.11	1.48	0.02
1	11	-0.107578E+08	0.124760E+07	-0.106003E+08	0.123396E+07	1.49	1.11	1.48	0.02
1	12	-0.103701E+08	0.171495E+07	-0.102030E+08	0.173490E+07	1.64	1.15	1.56	0.26

*** FULL VELOCITY SYMMETRY ***

Example Problem 4

The geometry for this example problem is the same as for example problem 1. In this example, the radiation impedance matrix relating surface forces and velocities and the field matrix relating far-field pressures and surface velocities are computed. It is assumed that the velocities have the same symmetry as the geometry. The results are to be written to an output file. The input file for this example problem is given below:

```
freq1=1500/(2*pi)
nblks=12
ai=1.68
ao=2.04
ht=1.2
htd2=.5*ht
rotlim=pi/nblks
end*params

rotational,nblks

circ_planar, htd2
ai,ao,-rotlim,rotlim
2,1,4,16
3,0,0,0

circ_cylinder, ao
-htd2,htd2,-rotlim,rotlim
4,1,4,16
3,0,0,0

circ_planar, -htd2
ai,ao,-rotlim,rotlim
2,1,4,16
-3,0,0,0

circ_cylinder, ai
-htd2,htd2,-rotlim,rotlim
4,1,4,16
-3,0,0,0

end*geom

freq, freq1, freq1, 0.

impedance matrix,1,1
```

farfield pressures,1,1,19
0,90,5,0,0,0

Example Problem 5

In this example problem, we consider a uniformly pulsating sphere of radius 1 m with a radial velocity of $1+i0$ m/sec. Figure 8 shows the geometry and breakup for this example problem. This example problem shows the need and use of interior points. We consider two frequencies corresponding to $ka = \pi/3$ and $ka = \pi$. The value $ka = \pi$ corresponds to an interior resonance where interior points are needed. The value $ka = \pi/3$ is well below the first interior resonance and, thus, does not require interior points. Let us first calculate the far-field pressures for these two frequencies with no interior points.

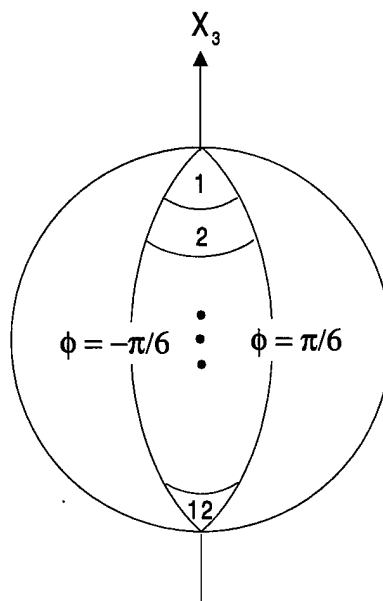


Figure 8. Geometry for example problem 5.

The input file for this calculation is shown below:

```
ka1=pi/3
ka2=pi
a=1.0
c=1500
fu=ka2*c/(2*pi)
fl=fu/3
finc=fu-fl
uu=pi/6
end*params

rot,6
sphere,1.0
0,pi,-uu,uu
```

```
12,1,4,16
```

```
3,0,0,0
```

```
end*geom
```

```
frequency,fl,fu,finc
```

```
! interior points,3
```

```
! 0,0,-.666667
```

```
! 0,0,0
```

```
! 0,0,.666667
```

```
rhs symmetry
```

```
vel(1:12,1,1)=1.0
```

```
! or read velocities from a file with:  velocity,tc5.vel
```

```
surface pressures
```

```
far-field pressures,1,1,4
```

```
0,180,30,0,0,0
```

The following pages show the output that would be obtained in the .out file for this problem.

REGION	NSEQNS	NSU	NSV	SUL	SUU	SVL	SVU	IORDRU	IORDRV
1	6	12	1	0.000000E+00	0.314159E+01	-.523599E+00	0.523599E+00	4	16

REGION - TRANSLATION (T1,T2,T3), IZAX

1	0.000000E+00	0.000000E+00	0.000000E+00	3
---	--------------	--------------	--------------	---

REGION - CCS

1	0.1000E+01	0.1000E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
---	------------	------------	------------	------------	------------	------------	------------	------------	------------

NO. OF SURFACE AREAS = 12 NO. OF SURFACE FIELD POINTS = 12

FREQUENCY= 250.0 RHO= 1000.0 C= 1500.0

SYMMETRY TYPE= ROT NO. OF BLOCKS= 6

FAR-FIELD PRESSURES (PHI,THETA,FFP(RL,IM,MAG,ANG) , NORMALIZED PATTERN, SOURCE LEVEL, DI)

0.00	0.00	-.256553E+06	0.105407E+07	0.108484E+07	103.68	0.00
0.00	30.00	-.256552E+06	0.105407E+07	0.108484E+07	103.68	0.00
0.00	60.00	-.256549E+06	0.105406E+07	0.108483E+07	103.68	0.00
0.00	90.00	-.256548E+06	0.105405E+07	0.108483E+07	103.68	0.00 *
						240.7
0.00	120.00	-.256549E+06	0.105406E+07	0.108483E+07	103.68	0.00
0.00	150.00	-.256552E+06	0.105407E+07	0.108484E+07	103.68	0.00
0.00	180.00	-.256553E+06	0.105407E+07	0.108484E+07	103.68	0.00

* DIRECTION FOR PATTERN NORMALIZATION

FREQUENCY= 750.0 RHO= 1000.0 C= 1500.0

SYMMETRY TYPE= ROT NO. OF BLOCKS= 6

FAR-FIELD PRESSURES (PHI,THETA,FFP(RL,IM,MAG,ANG) , NORMALIZED PATTERN, SOURCE LEVEL, DI)

0.00	0.00	0.195530E+06	-.187094E+08	0.187104E+08	-89.40	0.00
0.00	30.00	0.195501E+06	-.187095E+08	0.187106E+08	-89.40	0.00
0.00	60.00	0.195484E+06	-.187096E+08	0.187106E+08	-89.40	0.00
0.00	90.00	0.195506E+06	-.187094E+08	0.187105E+08	-89.40	0.00 *
						265.4
0.00	120.00	0.195511E+06	-.187096E+08	0.187106E+08	-89.40	0.00
0.00	150.00	0.195500E+06	-.187095E+08	0.187106E+08	-89.40	0.00
0.00	180.00	0.195495E+06	-.187094E+08	0.187104E+08	-89.40	0.00

* DIRECTION FOR PATTERN NORMALIZATION

Looking at the directivity index (DI) corresponding to $ka = \pi$ shows this answer is incorrect. Let us now rerun the same problem with three interior points located at $(0,0,-2/3)$, $(0,0,0)$, and $(0,0,2/3)$. The input file for this calculation is the same as the previous one, with the interior point control lines uncommented. The following pages show the output that would be obtained in the .out file for this example problem. It can be easily verified that the answers for this case are correct.

REGION	NSEQNS	NSU	NSV	SUL	SUU	SVL	SVU	IORDRU	IORDRV
1	6	12	1	0.000000E+00	0.314159E+01	-.523599E+00	0.523599E+00	4	16

REGION - TRANSLATION (T1,T2,T3), IZAX

1	0.000000E+00	0.000000E+00	0.000000E+00	3
---	--------------	--------------	--------------	---

REGION - CCS

1	0.1000E+01	0.1000E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
---	------------	------------	------------	------------	------------	------------	------------	------------	------------

NO. OF SURFACE AREAS = 12 NO. OF SURFACE FIELD POINTS = 12

FREQUENCY= 250.0 RHO= 1000.0 C= 1500.0

SYMMETRY TYPE= ROT NO. OF BLOCKS= 6

FAR-FIELD PRESSURES (PHI,THETA,FFP(RL,IM,MAG,ANG) , NORMALIZED PATTERN, SOURCE LEVEL, DI)

0.00	0.00	-.256550E+06	0.105407E+07	0.108484E+07	103.68	0.00
0.00	30.00	-.256550E+06	0.105406E+07	0.108483E+07	103.68	0.00
0.00	60.00	-.256547E+06	0.105406E+07	0.108483E+07	103.68	0.00
0.00	90.00	-.256546E+06	0.105405E+07	0.108482E+07	103.68	0.00 *
						240.7
0.00	120.00	-.256548E+06	0.105406E+07	0.108483E+07	103.68	0.00
0.00	150.00	-.256550E+06	0.105406E+07	0.108484E+07	103.68	0.00
0.00	180.00	-.256551E+06	0.105407E+07	0.108484E+07	103.68	0.00

* DIRECTION FOR PATTERN NORMALIZATION

FREQUENCY= 750.0 RHO= 1000.0 C= 1500.0

SYMMETRY TYPE= ROT NO. OF BLOCKS= 6

FAR-FIELD PRESSURES (PHI,THETA,FFP(RL,IM,MAG,ANG) , NORMALIZED PATTERN, SOURCE LEVEL, DI)

0.00	0.00	-.136194E+07	-.433640E+06	0.142931E+07	-162.34	0.00
0.00	30.00	-.136195E+07	-.433514E+06	0.142928E+07	-162.34	0.00
0.00	60.00	-.136195E+07	-.433457E+06	0.142927E+07	-162.35	0.00
0.00	90.00	-.136194E+07	-.433591E+06	0.142929E+07	-162.34	0.00 *
						243.1
0.00	120.00	-.136195E+07	-.433459E+06	0.142927E+07	-162.35	0.00
0.00	150.00	-.136195E+07	-.433514E+06	0.142928E+07	-162.34	0.00
0.00	180.00	-.136194E+07	-.433637E+06	0.142930E+07	-162.34	0.00

* DIRECTION FOR PATTERN NORMALIZATION

Example Problem 6

In this example problem, we consider the plane-wave scattering from a rigid sphere of radius 5 m and $ka = 5$, using two methods of geometry generation. Both methods use 6-th order rotational symmetry with 20 subdivisions per symmetry block. The first method generates the geometry using the sphere equations. The second method generates the geometry using axisymmetric finite element inputs. Figure 9 shows the target strength versus angle for both methods of geometry generation along with the results of an analytic series solution.

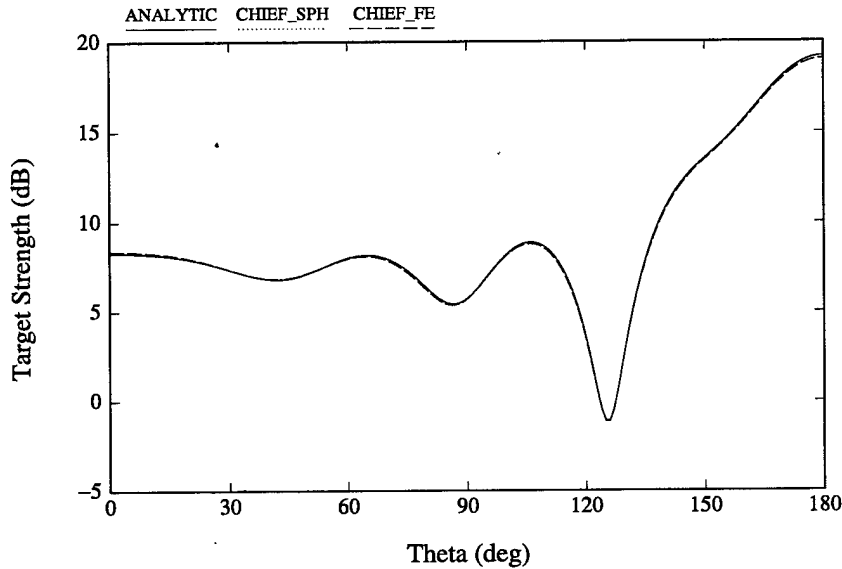


Figure 9. Target strength versus angle for a sphere ($ka = 5$).

The contents of the input file for the spherical geometry input is shown below:

```
nblks=6
c=1500
a=5
rka=5
freq=rka*c/(2*pi*a)
rotlim=pi/nblks

end*params

rot,nblks
sphere,a
0,pi,-rotlim,rotlim
20,1,4,16
3,0,0,0
```

```
end*geom
```

```
frequency,freq,freq,0  
surface pressures  
plane wave,1,1,0,0  
far-field,1,3  
0,180,2,0,0,0
```

The input file for the axisymmetric finite element input is exactly the same as above except that the geometry section is replaced by

```
rot,nblks  
fE_axisymmetric, tc6.crd, tc6.elc, 4, 16  
3  
end*geom
```

The contents of the nodal coordinate file tc6.crd are shown below.

1	0.0000E+00	0.5000E+01
2	0.3923E+00	0.4985E+01
3	0.7822E+00	0.4938E+01
4	0.1167E+01	0.4862E+01
5	0.1545E+01	0.4755E+01
6	0.1913E+01	0.4619E+01
7	0.2270E+01	0.4455E+01
8	0.2612E+01	0.4263E+01
9	0.2939E+01	0.4045E+01
10	0.3247E+01	0.3802E+01
11	0.3536E+01	0.3536E+01
12	0.3802E+01	0.3247E+01
13	0.4045E+01	0.2939E+01
14	0.4263E+01	0.2612E+01
15	0.4455E+01	0.2270E+01
16	0.4619E+01	0.1913E+01
17	0.4755E+01	0.1545E+01
18	0.4862E+01	0.1167E+01
19	0.4938E+01	0.7822E+00
20	0.4985E+01	0.3923E+00
21	0.5000E+01	-.2186E-06
22	0.4985E+01	-.3923E+00
23	0.4938E+01	-.7822E+00
24	0.4862E+01	-.1167E+01
25	0.4755E+01	-.1545E+01

26	0.4619E+01	-.1913E+01
27	0.4455E+01	-.2270E+01
28	0.4263E+01	-.2612E+01
29	0.4045E+01	-.2939E+01
30	0.3802E+01	-.3247E+01
31	0.3536E+01	-.3536E+01
32	0.3247E+01	-.3802E+01
33	0.2939E+01	-.4045E+01
34	0.2612E+01	-.4263E+01
35	0.2270E+01	-.4455E+01
36	0.1913E+01	-.4619E+01
37	0.1545E+01	-.4755E+01
38	0.1167E+01	-.4862E+01
39	0.7822E+00	-.4938E+01
40	0.3923E+00	-.4985E+01
41	-.4371E-06	-.5000E+01

The contents of the element file tc6.elc is shown below.

1	2	3
3	4	5
5	6	7
7	8	9
9	10	11
11	12	13
13	14	15
15	16	17
17	18	19
19	20	21
21	22	23
23	24	25
25	26	27
27	28	29
29	30	31
31	32	33
33	34	35
35	36	37
37	38	39
39	40	41

Example Problem 7

In this example problem, we illustrate the plane infinite rigid baffle option. The problem is to compute the radiation impedance of a half-wavelength diameter circular piston in a plane infinite rigid baffle. The impedance is to be calculated in CHIEF using four blocks of rotational symmetry with four radial subdivisions per block. The analytic solution for this problem gave the following result:

$$z = .952057 \times 10^7 + i.777030 \times 10^7.$$

To calculate the impedance with CHIEF we use a uniform velocity distribution of $1+i0$. The impedance is then equal to the complex power given in the .out file. The value computed with this breakup is

$$z = .957883 \times 10^7 + i.780259 \times 10^7,$$

which agrees with the analytic solution to within about 0.5%. The input file for this run is shown below:

```
freq=1500/(2*pi)
nblks=4
a=pi/2
rotlim=pi/nblks
end*params

rot,nblks
circ_planar,0
0,a,-rotlim,rotlim
4,1,2,6
3
end*geom

frequency,freq,freq,0

inf baffle

rhs symmetry

velocity,tc7.vel
! or vel(1:4,1,1)=1:0

surface,3
```

The velocity file tc7.vel is as follows

1	1	1	1.	0.
1	1	2	1.	0.
1	1	3	1.	0.
1	1	4	1.	0.

Example Problem 8

This example problem shows how to compute near-field pressures. The radiating surface consists of a circular cylinder with flat circular end pieces. The cylinder radius is 1 m and the height is 2 m. We choose the origin at the center of the cylinder and let the z -axis coincide with the cylinder axis. The end surface at $z = 1$ is given a velocity of $1+i0$ and the rest of the surface has zero velocity. We want to compute the pressure at the two points $(0,0,1.25)$ and $(0,0,1.5)$ on the axis near the piston. The input file for this problem is shown below:

```
freq1=100
frequ=1500
freqinc=1400
nblks=12
ao=1.0
ht=2.0
htd2=.5*ht
rotlim=pi/nblks
end*params

rotational,nblks

circ_planar, htd2
0,ao,-rotlim,rotlim
16,1,4,16
3

circ_cylinder, ao
-htd2,htd2,-rotlim,rotlim
32,1,4,16
3

circ_planar, -htd2
0,ao,-rotlim,rotlim
16,1,4,16
-3,0,0,0

end*geom

freq, freq1, frequ, freqinc

rhs symmetry

vel(1:16,1,1)=1.0

surface pressures
```

nearfield pressures,2,3

0,0,1.25

0,0,1.5

Note that you only have to input the nonzero velocities. The results from the file tc8.out are shown on the following page

REGION	NSEQNS	NSU	NSV	SUL	SUU	SVL	SVU	IORDRU	IORDRV
1	2	16	1	0.00000E+00	0.100000E+01	-.261799E+00	0.261799E+00	4	16
2	4	32	1	-.100000E+01	0.100000E+01	-.261799E+00	0.261799E+00	4	16
3	2	16	1	0.000000E+00	0.100000E+01	-.261799E+00	0.261799E+00	4	16

REGION - TRANSLATION (T1,T2,T3), IZAX

1	0.000000E+00	0.000000E+00	0.000000E+00	3
2	0.000000E+00	0.000000E+00	0.000000E+00	3
3	0.000000E+00	0.000000E+00	0.000000E+00	-3

REGION - CCS

1	0.1000E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	0.1000E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
3	-.1000E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

NO. OF SURFACE AREAS = 64 NO. OF SURFACE FIELD POINTS = 64

FREQUENCY= 100.0 RHO= 1000.0 C= 1500.0

SYMMETRY TYPE= ROT NO. OF BLOCKS= 12

NEAR-FIELD POINTS (X,Y,Z)

1	0.0000E+00	0.0000E+00	0.1250E+01
2	0.0000E+00	0.0000E+00	0.1500E+01

NEAR-FIELD PRESSURES (NFP(RL,IM,MAG,ANG) , NORMALIZED PATTERN)

0.643337E+05	0.389493E+06	0.394770E+06	80.62	0.00 *
0.643251E+05	0.290717E+06	0.297748E+06	77.52	-2.45

* DIRECTION FOR PATTERN NORMALIZATION

FREQUENCY= 1500.0 RHO= 1000.0 C= 1500.0

SYMMETRY TYPE= ROT NO. OF BLOCKS= 12

NEAR-FIELD POINTS (X,Y,Z)

1	0.0000E+00	0.0000E+00	0.1250E+01
2	0.0000E+00	0.0000E+00	0.1500E+01

NEAR-FIELD PRESSURES (NFP(RL,IM,MAG,ANG) , NORMALIZED PATTERN)

-.163006E+07	-.110086E+07	0.196698E+07	-145.97	0.00 *
-.267511E+07	0.117691E+07	0.292256E+07	156.25	3.44

* DIRECTION FOR PATTERN NORMALIZATION

Example Problem 9

This example problem is like example problem 2 except that both surface and far-field A and B matrices are output. In this case, it is not necessary to input a velocity distribution. The control section of the input file for this example is shown below:

```
freq, freq1, freq1, 0.
```

```
a_b matrices
```

```
surface matrices
```

```
farfield matrices,1,0
```

```
0,90,5,0,0,0
```

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APPENDIX: BASIC CHIEF THEORY

The principal quantity of interest in classical (linear) acoustics is the acoustic pressure $p(x, t)$ which is a function of both position and time. The acoustic pressure is the excess pressure over the hydrostatic pressure due to compressional waves in the medium. The acoustic pressure $p(x, t)$ satisfies the wave equation,

$$\Delta p = \frac{1}{c^2} \frac{\partial^2 p}{\partial t^2}. \quad (1)$$

Here, Δ is the spatial Laplacian operator and c is the speed of sound in the fluid medium. In acoustics, it is often more convenient to work in the frequency domain than in the time domain. By frequency domain we mean the Fourier transform domain. The Fourier transform P of p is defined by the pair of relations,

$$p(x, t) = \int_{-\infty}^{\infty} P(x, \omega) e^{i\omega t} d\omega \quad (\text{inverse Fourier transform}), \quad (2a)$$

where

$$P(x, \omega) = \int_{-\infty}^{\infty} p(x, t) e^{-i\omega t} dt \quad (\text{Fourier transform}). \quad (2b)$$

The transform variable ω is called the angular frequency, and the related quantity $f = \omega/(2\pi)$ is called the frequency. Note that whereas the pressure p is a real quantity, the transformed pressure P is, in general, complex. The Fourier transformed pressure $P(x, \omega)$ satisfies the reduced wave equation,

$$\Delta P + k^2 P = 0, \quad (3)$$

where $k = \omega/c$ is the acoustic wavenumber.

In scattering problems, the incident pressure p^{inc} is the pressure that would be present if the scattering object were removed. If the source of the incident pressure is far from the scattering object, p^{inc} is usually taken to be a plane wave since the wave is approximately planar in the vicinity of the scatterer. If p is the total acoustic pressure present in a scattering problem, then the scattered pressure p^{s} is defined by

$$p^{\text{s}} = p - p^{\text{inc}}. \quad (4)$$

Clearly, the incident and scattered pressures also satisfy the acoustic wave equation.

To uniquely determine the pressure, it is necessary to specify some initial and boundary conditions in addition to the requirement that the wave equation be satisfied. In the time domain, we usually specify initial conditions throughout the region of interest for both p and \dot{p} as well as boundary conditions on either p or the normal velocity v . In the frequency domain, these boundary and initial conditions are sufficient to uniquely determine p for exterior (unbounded region) problems. In the frequency domain, we usually specify either the pressure transform P or the normal velocity transform V on the boundary. For exterior

problems in the frequency domain, it is necessary to supplement the boundary conditions with a radiation condition at infinity to eliminate the possibility of waves coming in from infinity. This condition usually takes the form,

$$\lim_{r \rightarrow \infty} r \left(\frac{\partial P}{\partial r} + ikP \right) = 0, \quad (5)$$

due to Sommerfeld. In effect, this condition says that the pressure field looks locally like an outgoing spherical wave at large distances from the sound source. This condition can be eliminated if the fluid is assumed slightly lossy (complex sound velocity). If the incident field in a scattering problem is considered a plane wave, then neither the incident pressure nor the total pressure satisfies the outgoing radiation condition. Therefore, in scattering problems, the outgoing radiation condition is applied to the scattered pressure.

The CHIEF method for numerically solving acoustic problems is based on the reduction of a boundary-value problem for the wave equation in the frequency domain to an equivalent integral equation over the boundary surface. This integral equation is obtained from the Helmholtz integral relations:

$$\int_S \left[-i\omega\rho G(x, \xi) V(\xi) - P(\xi) \frac{\partial G}{\partial n}(x, \xi) \right] dS(\xi) = \begin{cases} -P(x) & x \text{ outside } S \\ -\frac{1}{2}P(x) & x \text{ on } S \\ 0 & x \text{ inside } S \end{cases} \quad (6)$$

where $G(x, \xi)$ is the free-space Green's function defined by

$$G(x, \xi) = \frac{e^{-ik|x-\xi|}}{4\pi|x-\xi|}, \quad (7)$$

n is the outward unit normal to S , and $|x-\xi|$ is the distance between x and ξ . These relations come from the divergence theorem, the fact that both P and G satisfy the wave equation, and the nature of the singularity of G . A good discussion of these integral relations is contained in [Baker and Copson, 1950]. If the normal velocity V is specified on the boundary S , then the middle relation in equation (6) provides an integral equation for the surface pressure P , for example,

$$\frac{1}{2}P(\zeta) - \int_S P(\xi) \frac{\partial G}{\partial n}(\zeta, \xi) dS(\xi) = i\omega\rho \int_S G(\zeta, \xi) V(\xi) dS(\xi) \quad \zeta \text{ on } S. \quad (8)$$

Once this integral equation is solved for the surface pressure, the pressure at any point in the exterior region can be obtained using the first relation in equation (6). However, for the exterior problem, there is an infinite discrete set of frequencies f_1, f_2, \dots for which the integral equation does not have a unique solution. It turns out that these frequencies are the resonance frequencies of the interior problem for the boundary condition $P = 0$ on S . As one might expect, numerical methods based on these integral equations have a problem when the frequency is close to one of these interior resonance frequencies. There is a large volume of literature describing various methods for overcoming this difficulty [Benthien and Schenck, 1997]. The resonance frequencies f_1, f_2, \dots are not resonances of the problem of interest.

There are no resonances of the exterior problem. In fact, the exterior problem has a unique solution at all frequencies. The interior resonance problem is a mathematical difficulty, not a physical one. What happens at these frequencies is that the integral equation is no longer equivalent to the original exterior acoustic boundary value problem.

CHIEF uses a piecewise constant approximation to the integral equation (8). In this approximation, the boundary surface S is subdivided into a finite number of subareas S_1, S_2, \dots, S_N . On each subarea S_n the pressure is approximated by a single value P_n and the normal velocity is approximated by a single value V_n . With this approximation the integral equation (8) becomes

$$\frac{1}{2}P(\zeta) - \sum_{n=1}^N P_n \int_{S_n} \frac{\partial G}{\partial n}(\zeta, \xi) dS(\xi) = i\omega\rho \sum_{n=1}^N V_n \int_{S_n} G(\zeta, \xi) dS(\xi). \quad (9)$$

Evaluating equation (9) at a set of reference points, $\zeta_1, \zeta_2, \dots, \zeta_N$ (one on each subarea), we obtain the system of equations

$$\sum_{n=1}^N A_{mn} P_n = \sum_{n=1}^N B_{mn} V_n \quad m = 1, 2, \dots, N, \quad (10)$$

where

$$A_{mn} = \frac{1}{2}\delta_{mn} - \int_{S_n} \frac{\partial G}{\partial n}(\zeta_m, \xi) dS(\xi), \quad (11)$$

$$B_{mn} = i\omega\rho \int_{S_n} G(\zeta_m, \xi) dS(\xi), \quad (12)$$

and δ_{mn} is the Kronecker delta defined by

$$\delta_{mn} = \begin{cases} 0 & m \neq n \\ 1 & m = n. \end{cases} \quad (13)$$

ζ_m is taken at the center of the m -th subarea. The system of equations (10) can be written in the matrix form,

$$AP = BV, \quad (14)$$

where P is an N -vector whose n -th component is P_n and V is an N -vector whose n -th component is V_n . If the velocities V_1, V_2, \dots, V_N are prescribed, then the system of equations (10) can be solved for the surface pressures P_1, P_2, \dots, P_N .

The expression in equation (6) for the pressure at an arbitrary field point can be approximated using the same discrete approximations, yielding

$$P(x) = \sum_{n=1}^N [A_n(x)P_n + B_n(x)V_n], \quad (15)$$

where

$$A_n(x) = \int_{S_n} \frac{\partial G}{\partial n}(x, \xi) dS(\xi) \quad \text{and} \quad B_n(x) = i\omega\rho \int_{S_n} G(x, \xi) dS(\xi). \quad (16)$$

This expression can be used to calculate the pressure at an arbitrary field point x once the surface pressures and normal velocities have been determined. Evaluating equation (15) at a set of field points x_1, \dots, x_M , we obtain

$$P(x_m) = \sum_{n=1}^N [A_n(x_m)P_n + B_n(x_m)V_n] \quad m = 1, \dots, M. \quad (17)$$

Equation (17) can be written in the matrix form,

$$P^{\text{fld}} = A^{\text{fld}}P + B^{\text{fld}}V, \quad (18)$$

where P^{fld} is the vector of field pressures, P is the vector of surface pressures, V is the vector of normal surface velocities, and the field matrices A^{fld} , B^{fld} are given by

$$A_{mn}^{\text{fld}} = A_n(x_m) \quad (19)$$

$$B_{mn}^{\text{fld}} = B_n(x_m). \quad (20)$$

CHIEF also contains far-field approximations for these field equations when the field points are far from the radiating surface. Equation (14) can be solved for P to obtain the impedance relation,

$$F = DP = ZV, \quad (21)$$

where D is the diagonal matrix of surface subdivision areas and Z is the impedance matrix given by

$$Z = DA^{-1}B. \quad (22)$$

Substituting equation (21) into equation (18), we obtain

$$P^{\text{fld}} = [A^{\text{fld}}D^{-1}Z + B^{\text{fld}}]V. \quad (23)$$

The matrix on the right-hand side of equation (23) is sometimes referred to as the field matrix.

In the vicinity of one of the frequencies for which the underlying integral equation does not have a unique solution, the system of equations (10) becomes numerically ill-conditioned. One method of overcoming this difficulty is to add some additional equations obtained by evaluating a discretized version of the last relation in equation (6) at a selected number of interior points. The overdetermined system of equations is then solved in a least squares sense. A more complete discussion of this approach to solving acoustic problems is contained in [Benthien, Barach, and Gillette, 1988].

While it is important to maintain the capability of handling quite general surfaces, it is also important to realize that significant reductions in computation time can be achieved by taking advantage of any symmetries that might be present in the problem. In the CHIEF approach, symmetry manifests itself in the structure of the A and B matrices. The previously referenced CHIEF manual shows that each type of symmetry results in the A and B matrices commuting with the appropriate symmetry operator Σ , for example,

$$A\Sigma = \Sigma A \quad \text{and} \quad B\Sigma = \Sigma B. \quad (24)$$

It follows from these commutation relations that the eigenspaces of Σ are invariant under both A and B . Thus, A and B become block diagonal when expressed in terms of a basis consisting of eigenvectors of Σ . The sizes of the diagonal blocks are the dimensions of the eigenspaces of Σ .

As an example of how symmetry is treated in CHIEF, consider the special case of one plane of symmetry. The symmetry operator for one plane of symmetry is

$$\Sigma = \begin{pmatrix} 0 & I \\ I & 0 \end{pmatrix}, \quad (25)$$

assuming that symmetric elements are numbered in the same order. The fact that A commutes with Σ implies that A has the block form,

$$A = \begin{pmatrix} A_1 & A_2 \\ A_2 & A_1 \end{pmatrix}. \quad (26)$$

The matrix X of eigenvectors of Σ is given by

$$X = \begin{pmatrix} I & I \\ I & -I \end{pmatrix}. \quad (27)$$

The inverse X^{-1} of X turns out to be $\frac{1}{2}X$. It is easily verified that $X^{-1}AX$ and $X^{-1}BX$ have the block diagonal form,

$$X^{-1}AX = \begin{pmatrix} A_1 + A_2 & 0 \\ 0 & A_1 - A_2 \end{pmatrix}, \quad X^{-1}BX = \begin{pmatrix} B_1 + B_2 & 0 \\ 0 & B_1 - B_2 \end{pmatrix}. \quad (28)$$

Thus, the equation $AP = BV$ can be written as

$$(X^{-1}AX)\hat{P} = (X^{-1}BX)\hat{V}, \quad (29)$$

where

$$\hat{P} = X^{-1}P \quad \text{and} \quad \hat{V} = X^{-1}V. \quad (30)$$

Equation (29) can be written in the partitioned form,

$$\begin{pmatrix} A_1 + A_2 & 0 \\ 0 & A_1 - A_2 \end{pmatrix} \begin{pmatrix} \hat{P}_1 \\ \hat{P}_2 \end{pmatrix} = \begin{pmatrix} B_1 + B_2 & 0 \\ 0 & B_1 - B_2 \end{pmatrix} \begin{pmatrix} \hat{V}_1 \\ \hat{V}_2 \end{pmatrix}. \quad (31)$$

Thus, the original system of equations reduces to the pair of smaller systems of equations:

$$(A_1 + A_2)\hat{P}_1 = (B_1 + B_2)\hat{V}_1 \quad (32)$$

$$(A_1 - A_2)\hat{P}_2 = (B_1 - B_2)\hat{V}_2. \quad (33)$$

Once these equations are solved, the solution of the original system of equations is obtained by

$$P_1 = \hat{P}_1 + \hat{P}_2 \quad (34)$$

$$P_2 = \hat{P}_1 - \hat{P}_2. \quad (35)$$

Since solution time goes roughly as the cube of the number of equations, it is faster by a factor of four to solve the two smaller systems rather than the one larger system. The symmetry can also be used to reduce the time needed to generate the matrices. The CHIEF program can take advantage of one, two, or three planes of symmetry as well as any finite order of rotational symmetry in the surface. CHIEF can also take advantage of symmetry in the velocity distribution when it exists. Table A-1 shows the time-reduction factors for various types of symmetry.

Table A-1. Time reduction factors in CHIEF for various types of symmetry.

Symmetry Type	Solution	Using velocity symmetry	Matrix generation
One plane of symmetry	4	8	2
Two planes of symmetry	16	64	4
Three planes of symmetry	64	512	8
<i>N</i> -fold rotational symmetry	N^2	N^3	N

The reader should see the appendix to the original CHIEF manual for more details on the theory behind the CHIEF program.

REPORT DOCUMENTATION PAGEForm Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE March 2000	3. REPORT TYPE AND DATES COVERED Final
4. TITLE AND SUBTITLE CHIEF2000 USERS MANUAL			5. FUNDING NUMBERS PE: 062314N AN: DN306257 WU: SUB4
6. AUTHOR(S) G. W. Benthien, D. Barach, and S. Hobbs			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) SSC San Diego San Diego, CA 92152-5001			8. PERFORMING ORGANIZATION REPORT NUMBER TD 3104
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of Naval Research ONR 321 800 North Quincy Street Arlington, VA 22217-5660			10. SPONSORING/MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES			
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			12b. DISTRIBUTION CODE
13. ABSTRACT (Maximum 200 words) This Users Guide explains the new CHIEF2000 computer program and describes the setup of the user-generated input file.			
14. SUBJECT TERMS Mission Area: Undersea and Antisubmarine Warfare boundary element method radiation integral equation scattering acoustics Helmholtz			15. NUMBER OF PAGES 116
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT SAME AS REPORT

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